

# **The Geographic Adaptive Potential of Freight Transportation and Production System in the Context of Fuel and Emission Constraints**

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by

**Janice Asuncion**

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## Abstract

Freight transportation is an integral element of various supply chains and has a complex and dynamical interrelationship with human economic activities. Modern logistical strategies paved way to the current supply chain organisation and logistics network design resulting in a more global economy and huge economies of scale. Recent trends of volatility of oil price have major implications in the movement of commodities across the supply chains. Likewise, climate change issues have presented urgent challenges in reducing carbon emissions for the transport and logistics sector. Pressure on the sector comes from both governments and consumers alike, demanding future sustainability as well as corporate environmental and social responsibility.

The original contribution of this research is to investigate the system-wide dynamics of freight transportation and production in the context of supply chains. A theoretical framework called the '*Geographic Adaptive Potential*' or GAP is built to understand how constraints in energy and emissions affect the production and distribution of commodities. The changes in the supply chain were investigated in four different components, namely a) the potential to shift to less energy and emissions intensive modes for long-haul freight, b) logistical strategies in the last leg of the chain or urban freight and c) local production and distribution, and d) the accessibility of potential customers to the markets.

The design of the GAP components is in correspondence with the links of the supply chain. The analyses yielded an evaluation of the adaptive capacity of the freight transport and production system. For long-haul freight, a GIS-based model was created called the '*New*

*Zealand Intermodal Freight Network'* or NZIFN. It is an optimisation tool integrating the road, rail and shipping network of New Zealand and calculates that minimum time, operating costs, energy and emissions routes between 2 given locations. The case studies of Auckland to Wellington and Auckland to Christchurch distributions of non-perishable products established that even a marginal increase of rail and coastal shipping share produced around 10% reduction in both freight energy and greenhouse gas emissions.

In the study of the last leg of the supply chain, the truck trip generation rates of different food stores were investigated. The strongest factors influencing the trip rates to a store are its size and product variation, the latter being a new parameter introduced in the dissertation. It is defined as the total number of brands for 6 chosen commodities commonly found in the stores. The trip rates together with the truck type and distance travelled were used to compute the freight energy usage of the stores. Results revealed that supermarkets consume the most energy for their delivery operations but relative to its physical size, they are more energy efficient than smaller stores. This is due to the utilisation of advanced logistical strategies such as freight consolidation and the effective use of distribution centres.

The localised production chapter was explored in the context of Farmers' markets and their difference with the conventional supermarket distribution system. Using a freight transport energy audit, the energy intensities of both systems were compared. The findings showed that Farmers' markets were more energy-intensive than supermarkets owing to the low volumes of goods delivered to the market and the lack of freight consolidation effort in the system.

The study on the active mode access of potential customers to both Farmers' markets and supermarkets captured the interplay between freight and personal transport and is the final component of GAP. The results of the ArcGIS based model called '*Active Mode Access*' or AMA demonstrated that both Farmers' markets and supermarkets have the same level of accessibility for walking or biking customers. However, the calculations also showed that almost 87% of New Zealanders have no AMA to stores and are at risk for fuel price increase.

Finally, the key result of this dissertation is the assessment that there is actually limited adaptive capacity of the freight transport and production system. This is due to network infrastructure and geographical constraints as well as commodity type and mode compatibility and other operational concerns. Due to these limitations, the GAP model assessed that reduction in energy and allowable emissions will ultimately reduce the amount of commodities moved in the system.

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Chapter 7 – Dr. Femke Reitsma for geospatial analytical methods of local food systems.

*This thesis is dedicated to...*

アーレン 拓海

## **Publications**

The bulk material of this dissertation is based on three publications of the author.

ASUNCION, J., PAGE, S., MURRAY, R. & KRUMDIECK, S. (2012 )

**Analysis of the Truck Trip Generation Characteristics of Supermarkets and Convenience Stores.**

*Institute of Professional Engineers New Zealand - Transport Group. Rotorua, New Zealand.*

ASUNCION, J., RENDALL, S., MURRAY, R. & KRUMDIECK, S. ( 2012)

**New Zealand Intermodal Freight Network and the Potential for Mode Shift.**

*Institute of Professional Engineers New Zealand - Transport Group. Rotorua, New Zealand.*

ASUNCION, J., RENDALL, S., MURRAY, R., PAGE, S. & KRUMDIECK, S. (2013)

**The Geographic Energy Adaptive Potential of the Farmers' Market System as Compared to the Conventional Supermarkets System.**

*Transportation Research Board, 2013 Washington D.C.*

It is also adapted from the research proposal and mini-thesis entitled:

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## Glossary of Terms

**Accessibility:** a measure of the spatial distribution of activities about a point, adjusted for the ability and desire to overcome spatial separation. The spatial separation is in the form of transport impedance or attractiveness of the location.

**Food Miles:** the network distance travelled by the food from its origin of production until it reaches the consumer.

**Geospatial Data:** information pertaining to a geographical location and characteristics of natural or constructed features and boundaries on the earth, represented by points, lines and polygons.

**Geographic Information Systems (GIS):** computer systems designed to capture, store, manipulate, analyse and graphically present all types of geographical data.

**Household:** person or group of persons who reside together in a domicile with shared facilities.

**Impedance:** In transportation, this parameter acts as a resistant to the direction of flow and is usually measured in terms of distance, time or monetary cost.

**Intermodal transportation:** an integrated system of freight transport involving two or more modes where cargo is shipped using the same loading unit.

**Life Cycle Analysis (LCA):** comprehensive assessment that identifies the energy, material, and waste flows of a product and their impact to the environment.

**Linear Programming (LP):** a mathematical method used to solve optimisation problems (maximisation or minimisation) using linear functions subject to a set of constraints.

**Logistics:** framework for planning, implementation and control of the efficient and effective storage of goods, services and related information from an origin to a destination.

**Multimodal transportation:** movement of goods involving two or more modes.

**Service Areas:** regions that encompass all accessible streets within a specified impedance parameter from (or to) a given facility.

**Sustainability:** the capacity to support and maintain living in the present generation without compromising future generations.

**Twenty-foot Equivalent Units (TEU):** an inexact measure used for the capacity of a container or ship's cargo in freight transport.

**Trip:** A single or one-direction vehicle movement with either the origin or destination (exiting or entering) a given location.

**Truck Trip Generation (TTG):** measure of the number of truck trips originating in or destined for a particular location.

**Urban Form:** refers to the spatial imprint of an urban transport system as well as the adjacent physical infrastructures.

**Vehicle Routing Problem (VRP):** a combinatorial optimisation problem that seeks the design of optimal delivery from one or several depots to service a number of geographically scattered customers with a fleet of vehicles.

## List of Acronyms

**AADT:** Annual Average Daily Traffic

**AMA:** Active Mode Access

**DC:** Distribution Centre

**EECA:** Energy Efficiency and Conservation Authority

**EU ETS:** European Union Emission Trading Scheme

**FHWA:** Federal Highway Administration

**FM:** Farmers' Markets

**FTE:** Full-Time Equivalent Employees

**GAP:** Geographic Adaptive Potential

**GIS:** Geographic Information Systems

**GIFT:** Geospatial Intermodal Freight Network

**IEA:** International Energy Agency

**JIT:** Just-in-time

**LINZ:** Land Information New Zealand

**MB:** Mesh Blocks (Units)

**NZTA:** New Zealand Transport Agency

**NZIFN:** New Zealand Intermodal Freight Network

**O-D:** Origin-destination (pair)

**TAs:** Territorial Authority (Units)

**TEU:** Twenty-foot Equivalent Units

**TTG:** Truck Trip Generation

**VRP:** Vehicle Routing Problem

## Chapter 1: Introduction

### 1.1 Background

Freight transportation is a broad field tied up with economics, policy making and society as it is an integral element of various supply chains and to some extent a vital factor in determining the quality of life of mankind. The interrelationship and interdependence of freight and the economy is complex and dynamic and to understand the scale of contribution and impact of freight to the economy, it is necessary to see freight transport from the supply chain and logistical context.

In the current paradigm, freight transportation plays a key role in today's economies allowing production and consumption to take place at locations that are geographically far from each other. This promotes a more competitive market as it stimulates a healthy competition among manufacturers and for companies to exploit economies of scale and aim for the geographic fragmentation of production wherein companies seek for overseas opportunities to take advantage of lower wages and more-relaxed employment policies in developing countries. Finally, products (both perishable and non-perishable) are now available worldwide with fast, efficient and streamlined operations and shipments.

However, the positive impacts of freight movements to the economy also yield detrimental effects to the environment and human health. Greenhouse gases such as carbon dioxide (CO<sub>2</sub>) is strongly linked to the problems of climate change which may result in temperature and precipitation changes, sea level rise and other extreme scenarios (Intergovernmental Panel on Climate Change, 2011). Other pollutants such as particulate matter (PM<sub>10</sub>) and

sulphur oxide (SO<sub>x</sub>) are associated with human health problems such as increased asthma and other respiratory issues (Katsouyanni K, 1997). At the same time, movements of goods by road also contribute to urban congestions and poses safety issues to other motorists and pedestrians.

Another key issue of freight movements in the current scheme is its sustainability in the future as the ultimate quest for economic growth and development hinges on cheap energy sources. Petroleum, which is a fossil fuel, is the primary fuel for freight movements of commodities accounting for 35% of all transport energy (Ribeiro and et al, 2007). The peaking of world oil production is forecast to fall within the decade from 2005-2015 and before 2030 (International Energy Agency, 2008). The average forecast results of 12 credible studies point to 2014 as the year of global peak oil (Aftabuzzaman and Mazloumi, 2011). Though some optimists are giving a much later date (e.g. 2040), the fact remains that oil is a finite resource and will imminently reach its plateau after some time and from that point onwards will continue to decline (Hirsch et al., 2006). Peak oil does not mean that the world runs out of oil, but that the rate of global production cannot grow any further and will be unable to meet the global demand, bringing escalated costs and disrupting the production and delivery of goods and services (Lerch, 2008).

## **1.2 Motivation**

A report published by the United Kingdom Energy Research Centre analysis deduced that there are only two mitigation strategies addressing the issue of the decline in fuel supply namely substitute energy sources and demand reduction (Sorell et al., 2009). The first option entails finding substitutes for oil in the form of other energy sources such as solar,

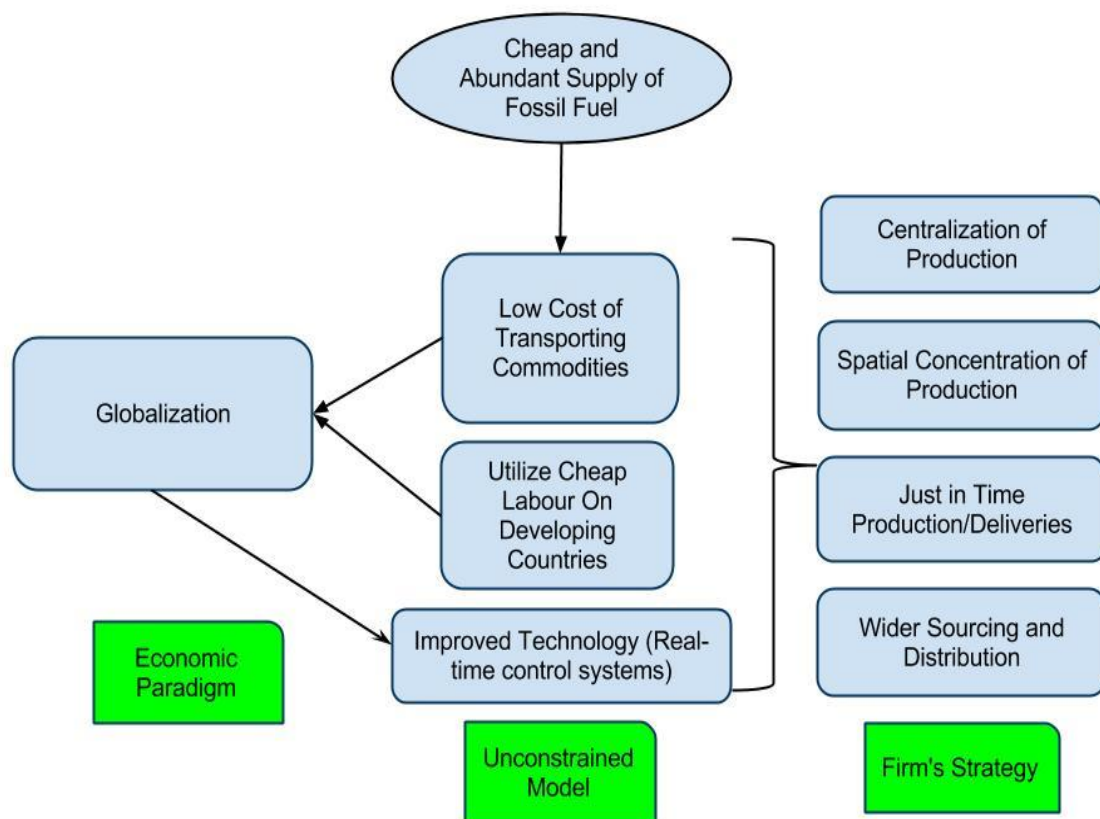
wind, hydrogen, bio fuels, amongst others. However given the current levels of technology and efficiency ratings, alternative sources of energy will not be enough to substitute for oil (Krumdieck and Dantas, 2008, Krumdieck, 2011). In fact, resorting to bio fuels will compete with food production, disrupt the whole food supply chain and would be impossible to substitute all fossil fuels for transport (Peters, 2008, Ajanovic, 2009).

The second option is to reduce the current levels of energy demands through a restructuring of the current economic patterns which would stop over-reliance on oil. One possibility for this option is the shift to more efficiently engineered vehicles or fleets, as well as the utilisation of more cost-effective renewable energy sources. However, the long-term approach in the reduction of energy demands is through the spatial and structural transformation of human economic activities and an overhaul in the logistics organisation from production to consumers (Hesse, 2008).

Figure 1.2.1 illustrates the current economic model of how cheap oil affects logistical strategies of companies paving way to globalisation. The motivation of this research is to formulate a model of an analogous hypothetical constrained system with expensive fossil fuels and higher tariffs on emissions as presented in Figure 1.2.2.

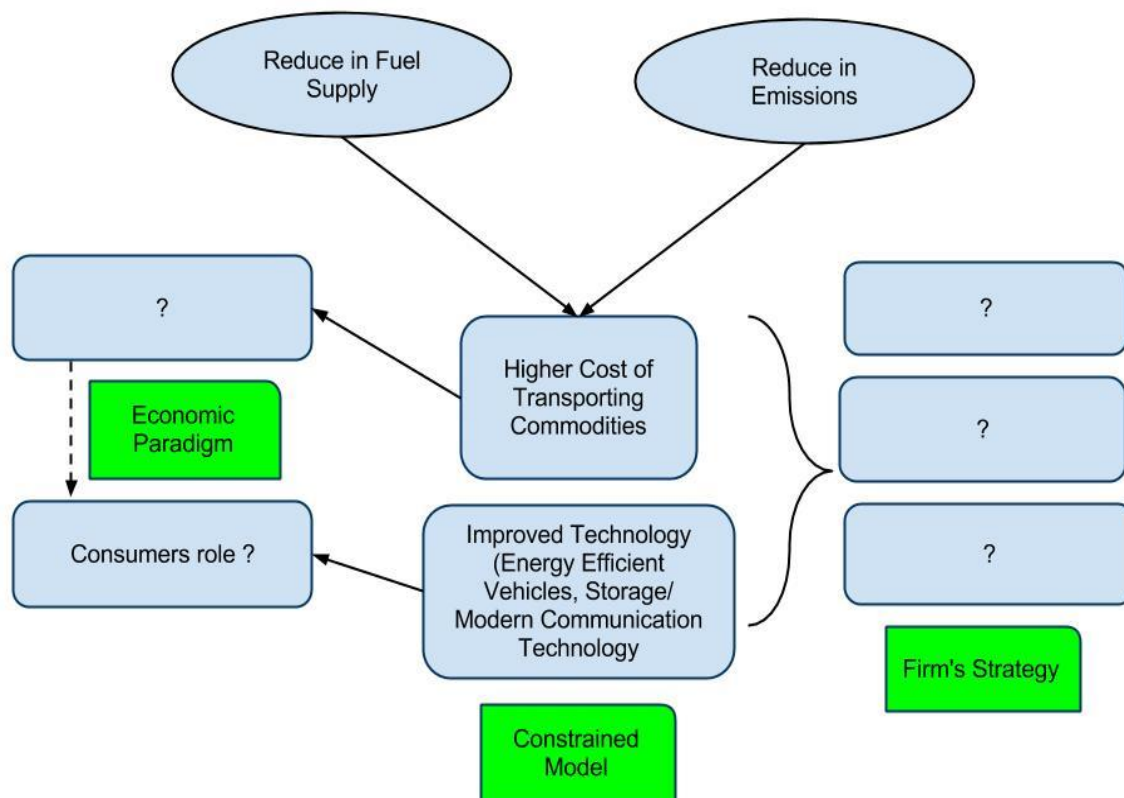
We seek to understand the changes in the system dynamics in the different components of the current oil-dependent paradigm. In accordance to the changes in the supply and distribution aspects, people are also expected to be aware and able to reengineer their lives and adapt to a world of growing energy scarcity (Rubin, 2011). Consumer behaviour has significant impact on the system and is also a driving force in fundamental structural changes in the economic paradigm.

As logistical strategies transition from economies of scale back to localised and labour-intensive era, people will also have to adapt their lifestyles in the post-peak oil and low carbon era. This implies living in places where there is better access to the basic services of their communities and having their essential goods coming locally (North, 2010).



**Figure 1.2.1 : The economic paradigm of cheap and abundant fossil fuels**





**Figure 1.2.2 : Hypothetical economic model with constraints on energy and emissions**

### 1.3 Problem Statement and Contribution

The original contribution of this research is to investigate the system of freight transport and production in the context of constraints on supply of fuel and tighter restrictions on emissions. A model framework called the 'Geographic Adaptive Potential' or GAP is developed which examines the different links or legs on the supply chain and their geospatial properties. By investigating the different aspects of the system dynamics, we assess the potential capacity for improvements in energy efficiency and environmental

performance of commodity movements. In this light, the system-wide changes are viewed as mitigation strategies for an energy-constrained and low-carbon scenario.

Four strategies are discussed in this dissertation namely a) shift to less-energy and emission intensive modes for long-distance freight haulage, b) last-leg logistic process improvements such as freight consolidation and reduction of truck trips, c) localised production or shortening the links of the supply chain, and d) better access for customer to the facilities. These strategies are dependent on many factors including the actual specifics of the studied scenario, type of goods, location, and time, amongst others.

The unique aspect of this research is that the components of the GAP model are all independent of behavioural and economic factors and instead used purely geographical parameters. Even though supply chain design and elements are intrinsically of economic nature and both suppliers and consumers behaviour and preference heavily influenced by (or a direct result of) supply chain logistic strategies, a geographic approach is a highly objective or impartial method of study. It is for this reason that the GAP model examines the potential for change instead of providing forecasts for this kind of changes.

This project aims to contribute to the effort of the Advanced Energy and Material Systems Laboratory summarised in (Krumdieck, 2011) which proposes the appropriate transition engineering tools comprising of models and analysis that efficiently reduce vulnerability and risk, increase adaptive capacity and build long-term resilience to diminishing oil supply scenarios. In particular, this dissertation may serve as a manual for transition engineering in the broad area of freight transport.

## **1.4 Significance of the Study**

This research is a theoretical contribution to the literature of transportation and logistics as it provides a framework on a topical subject of sustainability of the current economic models of growth and development in terms of global production and distribution. As we explore the fundamental characteristics of freight transport and production system, we are able to envision plausible scenarios and changes in the era of energy scarcity and low-carbon world. Moreover, our results are also of practical value since our analysis uses both existing and survey-obtained New Zealand data. Our research output is beneficial to both the private and public sector.

The four models presented in this dissertation pertaining to the different links in the supply chain could serve as a valuable tool in evaluating decisions and planning strategies in the strategic, tactical and operational levels of business establishments. We assessed the potential benefits of intermodal freight transportation, logistical strategies such as freight consolidation and trip chaining, localised sourcing or production, and evaluated the access of customers to the stores. As for the public sector, the results will be useful in determining the policies supporting its local industries and also in aiding businesses by providing the appropriate infrastructures and assistance in terms of tax credits or benefits.

## 1.5 Rationale of the Study

There is an abundance of literature on freight transportation in the supply chain context including optimisation strategies for reducing cost and time. This is because the primary function of logistical strategies in the chain is to deliver the right product at the right time with minimum cost. Furthermore, logistical efficiency in the supply chain was associated with four major trends namely, centralisation, spatial concentration of production, wider sourcing and distribution, and just-in-time production and deliveries. Although these trends reflect results of sophisticated optimisation operations research algorithms, their main objectives were to minimise the cost of operations and time and seldom account for the possible constraints on energy and emissions brought about by diminishing fuel supply and restrictions on greenhouse gases.

Econometric models using long-term analyses of the markets are also primarily used to address the questions and provide innovative solutions in the era of energy scarcity. However, these models are based on a lot of factors including socio-economic parameters that influences the behaviour, attitude and motivation of the consumers as well as the transport and logistics sector. This kind of behavioural analysis is non-deterministic and requires guesses or estimates to diagnose the response to a given scenario.

In contrast, our proposed methodologies are non-predictive in nature. They are designed to measure the adaptive potential by examining the geographic parameters that allows alteration in the system dynamics rather than the willingness to be eco-aware and preference to reduce energy consumptions and emissions.

## 1.6 Scope and Limitations of the Study

Our research approach on models for freight transport and logistics will cover several disciplines related to freight transportation. The flow of the literature discussion will involve topics from various areas of studies which we will merge together to provide a concrete and substantial foundation in building a geographic-based tool in analysing freight transportation and production with constraints on fuel and emissions. Our study will deviate from the usual approach of accounting for economic and behavioural dimensions of the supply chain. The hypotheses presented are exploratory in nature, which will be backed-up by both computational and analytical case studies and limited within New Zealand.

Thereby actual model validation for other geographical locations and in the worldwide setting is not conducted in this stage of the research. Nevertheless, the related literature discussion covers trends in other developed countries which are also occurring in New Zealand.

Finally, topics such as peak oil, climate change and local food systems have always been associated with the concept of 'Sustainability.' However, we would like to emphasise that the dynamics of freight transport discussed in this thesis is just a minute facet in the myriad of dimensions in the complex realm of sustainability where social, ecological, political, economic and human health factors come into play. Thus, instead of making prescriptions about sustainability measures when fuel supply is reduced and there are stricter regulations on greenhouse gas emissions, we present an objective analysis which may or may not be in line with sustainability measures, based on geospatial parameters of (and interactions between) the systems' components.

## **1.7 Organisation of the Thesis**

The structure of this research entails extensive literature and data review hence two chapters are allotted for them, one with focus on general commodity supply chains and freight while the other pertains specifically to previous freight studies and methodologies applied to New Zealand.

Chapter 2 reviews related literature on supply chain, logistics network and freight transportation models. It presents an illustration of the supply chain and logistical patterns affecting freight transportation.

Chapter 3 presents the existing freight literature in New Zealand and includes data and statistics from various research institutions and organisations. We also give an overview of the freight network infrastructure used in the country as well as current trends in freight operations and freight energy usage.

Chapter 4 provides the conceptual framework and research methodology used in the study. Here, the concept of the Geographic Adaptive Potential or GAP of the supply chain system is introduced with its design specifically formulated to target the different links in the commodity chain.

From here on, one chapter is allotted for each of the four components of the GAP model presented.

Chapter 5 presents the use of Geographic Information Systems (GIS) to visualise and analyse intermodal freight transport through the creation of the New Zealand Intermodal

Freight Network (NZIFN) model. The study encompasses long-distance freight movements usually of bulk commodities and concludes with the potential benefits and savings of shifting to less energy and emissions-intensive modes such rail and coastal shipping.

Chapter 6 investigates the last leg of the supply chain by analysing the truck trip generation characteristics of the different food distribution systems in New Zealand and how differences in the stores' physical and operational characteristics, including distribution patterns affect fuel intensity.

Chapter 7 describes the local food system in New Zealand thru data collected from Farmers' markets. A case study audits the traceability of products in the local supply chain to distinguish it from the convoluted supermarket system. A hypothetical model for freight consolidation for localised food production is given to incorporate the strengths of the supermarket system in the Farmers' market setting.

Chapter 8 explores the link that ties freight with personal transport. The chapter presents a GIS-based model that calculates the potential accessibility of the customers to supermarkets and Farmers' market.

Chapter 9 concludes with the results of the study and recommends extensions and directions of the research in the future.

## **Chapter 2: Review of Related Literature**

This chapter examines the fundamental definitions of logistics and the supply chain and the methods used in modelling goods movements. Bringing products from primary producers to end-users is a very complicated and dynamic process. It involves decisions and policies influenced by the stakeholders of the different levels in the supply chain and are driven by distribution strategies that minimise transportation and inventory costs (Burns et al., 1985). These strategies are dependent on key aspects such as technological improvements, labour availability, costs and the price of fuel.

### **2.1 The Supply Chain**

A supply chain is a complex system made up of facilities, linked by transportation services in which raw materials are converted into finished products through manufacturing, processing and packaging and then distributed to the final users. It includes primary producers (suppliers), manufacturing centres, warehouses, Distribution Centres (DCs) and retail outlets. At its highest level, a supply chain is comprised of two basic integrated processes (Beamon, 1998):

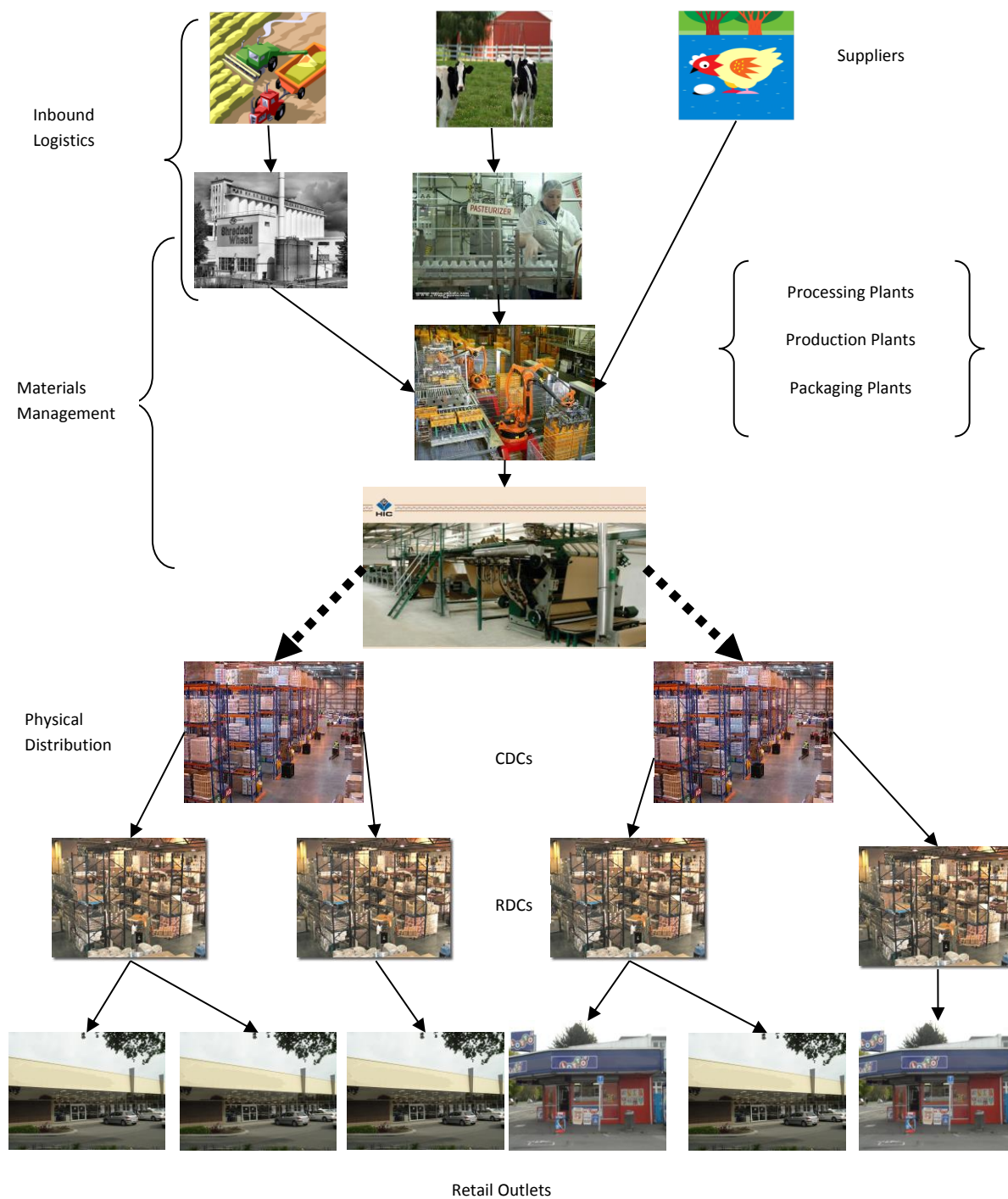
- 1) Production planning and inventory control process
- 2) Distribution and logistics process

Figure 2.1.1 shows a typical supply chain in which the production and distribution systems are made up of two stages each. In the production system, two farm products (wheat and

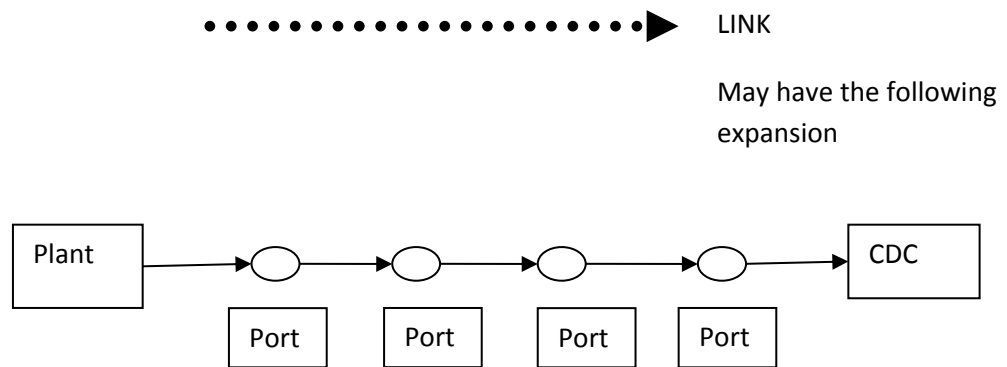


dairy) undergo a processing stage while the eggs are sent directly to the production plant, where bread is made. The product is then sent to a packaging plant where it is labelled and sealed. The distribution system consists of two central distribution centres (CDCs) supplied either directly or indirectly by the packaging plant, which in turn replenish two regional distribution centres (RDCs) each. Each of the transportation links in Figure 2.1.1 could be a simple transportation line (e.g. truck line) or a more complex transportation process involving additional facilities (e.g. port terminals) and companies (e.g. truck carriers). This is illustrated in Figure 2.1.2.

There is a distinction between the traditional warehouse and DCs. Warehouses are used mainly for product storage and results from the imbalance between patterns of production and consumption and warehouses serve as buffer for firms to accommodate the spikes and lulls in the sales process. In contrast, DCs are more flow-and-throughput oriented for economies of scale and replaces the use of several warehouses in different locations with one or two large facilities (Murphy and Wood, 2008).



**Figure 2.1.1 : Typical supply chain diagram**



**Figure 2.1.2 : Multiple links from plants to distribution centres**

## 2.2 Global Supply Chains

Global supply chains are highly complex and interdependencies amongst its components necessitate an efficient distribution and logistics process paving way for a geographically integrated economy. Here, comparative advantages of a region are exploited in terms of procurement of the cheapest and most accessible raw materials while manufacturing and assembly are performed in regions having the lowest labour costs or human resource skills specialization (Rodrigue et al., 2006).

Here, we present the four logistical trends that affect freight transport operations arising from a geographically integrated supply chain (McKinnon et al., 2002):

### 2.2.1 Centralisation

Logically, companies would aim to minimise the total transportation and inventory costs hence a coordinated effort on the different levels of operations is necessary which is the

essence of Supply Chain Management. Centralising production entails fewer and larger distribution centres or warehouses and allows firms to cut down on inventory costs.

A case study of Scottish Brewers in Scotland shows considerable savings on labour and inventory costs, property-related expenses and even truck haulage costs (as a result of consolidation of brewery to depot flows) through centralisation. Evidently, there is an expected increase in local delivery costs but the savings in labour wages were more than enough to offset this rise (McKinnon et al., 2002).

Meanwhile, a comparative study of centralised and decentralised plant distribution of Siam Cement Company in Thailand showed that the decentralised system is the more efficient option and it also cuts down on CO<sub>2</sub> emissions (Raothanchonkun and Hanaoka, 2005).

Another aspect of the centralisation trend is that with DCs and RDCs ranging from 50,000 – 100,000 sqm, conflicts with land-use planning and infrastructure provision can no longer be accommodated in gateway regions and nearby urban areas, thus necessitating new location requirements such as cheap land and transport and accessibility to these distant places (Hesse, 2008, Ryan, 1999, Erickson, 2001) .

### **2.2.2 Spatial Concentration of Production**

In line with the concept of centralised production, manufacturers also concentrate their production plants and factories in fewer locations. This allows companies to maximise economies of scale in the production operation at the expense of the strain on the transportation network.

In the UK, spatial concentration of economic activities may be subsiding although there is still a significant pressure for further centralisation and a survey of 100 large British manufacturers are aiming for 15% and 40% reduction of their warehouses in UK and Europe, respectively (McKinnon and Woodburn, 1996, Debenham Tewson & Chinnocks, 1993).

### **2.2.3 Wider Sourcing and Distribution**

Freight traffic has been growing as a result of structural changes in the production and distribution systems and not because of an increase in the physical mass of goods in the economy (McKinnon and Woodburn, 1996). The growth in freight traffic has occurred mainly as a result of two processes:

- 1) Increase in the number of links in the supply chain or the number of separate freight journeys between raw material source and final point of sale. This is also termed as the 'Handling' factor which measures the number of separate freight journeys that a consignment makes in moving raw material source to final point of sale.
- 2) Increase in the length of links or average length of haul.

The wider distribution scale is sustained by the geographic fragmentation of production or separation of different production tasks. With advents in information technology, businesses are able to relocate certain production tasks to foreign countries. The trends in geographic fragmentation is the main driver of growth of global trade and movement of commodities in the international scale (World Economic Forum, 2012).

### 2.2.4 Just-in-Time Production and Deliveries

In the 21<sup>st</sup> century, businesses have adapted the concept of “Just-in-time” (JIT) production in managing supply chains. This strategy is to synchronise transportation of goods in the different levels of the supply chain with the production process and aims to reduce in-process inventory and overhead costs. Some experts claim that small and frequent deliveries by JIT would increase inbound transportation costs. However it was shown in (Tracey et al., 1995) that it is possible for JIT firms to have lower transportation costs than non-JIT firms.

The main problem with this approach of evaluation is the externalisation of a large part of the transportation costs in which these are transferred to the public infrastructure and the environment. In other words, society is indirectly paying for the freight shipments through taxes (Boge, 1995).

The logistical trends outlined above showed that transportation costs are not the primary agenda in the strategic decisions of firms as cheap and abundant fuel allows production and sourcing from more distant locations. However, freight transportation often accounts for even two-thirds of the total logistics costs from a study in EU countries (Ghani et al., 2004). Hence, it should also play a key role in logistics system management.

Here, we outline several ways to improve the logistics efficiency through the transportation component.

- 1) **Compare methods of deliveries** such as direct shipping (shipping separate loads from supplier to its customer in the supply chain) and peddling (deliveries to more than one customer) (Burns et al., 1985).

- 2) Reduce empty running of trucks:** The factors and constraints for reducing empty trucks or back loading were explored in (McKinnon, 2006b).

The factors that contribute to higher rates of back loading are more geographically balanced traffic flows, longer length of haul, reverse logistics, use of load matching services and integration of primary distribution with secondary distribution. It was hypothesised that the use of third-party logistics (3PL) or transport outsourcing would achieve higher levels of back loading than own operators but this argument was found to be flawed in (McKinnon, 2006b). Also, a study of 61 past students and executives of the Institute of Logistics in UK showed that some companies found that 3PL are too expensive (Croucher, 1998).

The main constraint in back loading is time as it increases the risk that the vehicle will not be re-positioned in time to collect its next outbound load (McKinnon, 1996). In operational terms, back loading is generally only feasible when there is sufficient slack in the schedule. With unpredictability in road traffic congestions, managers do not have the confidence in the back loading system. Another reason why back loading is not always feasible is the incompatibility of vehicles and products especially for goods with specific handling characteristics (McKinnon, 2006b).

- 3) Freight consolidation:** With economies of scale and coordination between different suppliers, shippers and customers, it is possible to consolidate small shipments into larger ones and reduce the number of necessary truck trips.
- 4) Third-party logistics (logistics outsourcing):** The use of third-party freight forwarders instead of their own fleet of vehicles will enable the shipper to focus on their core competencies especially in the case when an organisation has an

inefficient distribution network such as workforce limitations, outdated warehousing facilities or information systems (Murphy and Wood, 2008).

- 5) Modal Shift:** When selecting a carrier, a shipper takes two fundamental parameters into account: cost and transit time. The increase of demand for “just-in-time” delivery, speed and flexibility obviously favours road as the primary means of transporting goods especially in the case of perishable goods and high-value goods are also better served by road. Moreover, infrastructure constraints meant that some destinations can only be reached by road.

This subject will be discussed in detail in the Section 2.4 (multi-modal networks).

## 2.3 Modelling Freight transportation

As with modelling passenger transport, freight models are based in spatial interactions between an origin and a destination, which is a transport demand/supply relationship. However, compared with passenger transport, freight transport received significantly less attention and is considered a newer discipline. However recent trends have shown that the field is growing in different directions and methodologies because of its role in the economy. Freight is tied to almost every area of the industry, produces major impacts on traffic congestion and the environment and poses risks to people’s health and safety.

Modelling freight movements is more complicated than passenger transportation because in the latter the passenger is in most part the decision maker, while in freight transport, there are multiple dimensions to be considered as such the type, volume and weight of goods and the number of trips. These layers give rise to two categorisation of models namely, a) commodity-based model which measures tonnage of the goods moved, and b)



trip-based model which counts the actual vehicle trips needed (Holguin-Veras and Thorson, 2000).

Both models have their own strengths, for the commodity-based model, since freight demand is determined by the different types of materials that need to be shipped to different locations then a measure of the volume of the goods transported is necessary (Luk and Chen, 1997). On the other hand, trip-based models have an advantage in terms of data collection with new equipment for traffic counts and the development of GPS units placed inside the vehicles (Holguin-Veras and Thorson, 2000). In general, commodity-based models measure the generation of demand in a particular location and are supply-chain oriented while vehicle-based models are products of logistic decisions involving various stakeholders in the operations and are also more useful for traffic planners and transport-policy makers (Holguin-Veras et al., 2011).

Another classification of freight models is the aggregate and disaggregate approach (Winston, 1983). The majority of the state-of-the-practice models utilised the aggregate kind owing to the scarcity and commercial sensitivity of available data. It is simpler and follows the traditional four-stage transportation modelling (Pendyala et al., 2000, Ortuzar and Willumsen, 2001). However, one major disadvantage of the aggregate models is that they tend to have focus more on freight generation and attraction and neglect the modal split component (Samimi et al., 2010).

One example of a highly-aggregated freight model is through Materials Flow Analysis (MFA) which aims to explain the scale of transport activity by linking material flows to socioeconomic activities of environmental relevance (Fischer-Kowalski et al., 2006). These

environmental impacts include energy consumption, carbon dioxide emissions, noise, and land-use.

Meanwhile, disaggregate models are better at capturing the behavioural complexities of modal selection decisions and are also flexible with the construction of utility functions taking into account highly-specific details (Regan and Garrido, 2001). These include characteristics of transport services, attribute of goods to be transported, market characteristics, and the attributes of the shipping firm (Ortuzar and Willumsen, 2001). The specific characteristics of the firm are the main factors that contribute to the firm's decision-making process in optimising their behaviour (Winston, 1983).

Time series analysis of past historical data trends is a straight-forward way to predict future freight flows and may use simple growth factor models to more complex autoregressive integrated moving models as discussed in (Cambridge Systematics Inc. NCHRP Report, 1997).

Another popular method in modelling freight is the economic input-output (IO) methods which involve the use of economic input and output indicators (Young et al., 1982, Zlatoper and Austrian, 1989, Voigtlaender, 2002). The model aims to determine the levels of economic activity that drive freight transportation demand such as capital, employment, land and other basic resources adding value through economic activities. These parameters are used as input values to the IO analysis matrix to determine economic outputs such as production and attraction of goods and services which are then used to estimate freight demand for a given geographic location.

Regardless of the classification, models should incorporate numerous decision makers in the supply chain as well as those involved in the actual physical distribution of goods such as the drivers, dispatchers, freight forwarders and transfer operator all of whom interact in a fast-paced vibrant environment. There is also a demand for models that can forecast alternative policy scenarios and linked to environment, land-use as well as security and risks (Lahsene et al., 2006).

### **2.3.1 Aggregate Freight Demand Modelling**

Here we will review the traditional 4-step approach in transportation modelling namely:

- Freight generation and/or Freight trip generation
- Trip distribution
- Modal split
- Trip assignment

#### **Freight Generation and Freight Trip Generation**

Freight generation (FG) or Freight trip generation (FTG) is the first step in modelling and understanding the impacts of freight on the urban congestion, pollution, safety, and the strain on the transportation network. In most studies such as (Paling, 2008) and (Bolland, 2005), freight generation rates are given for large aggregated sectors. In some cases, this falls short in providing the necessary micro-level accuracy of the trucking activities in specific sub-industries.

For the private sector, freight trip generation is a result of complex strategic, tactical and operational business decisions which in general aims to reduce the costs of operations and maximize profits. Logically, firms would seek to optimise their distribution systems so that the total transport and warehousing costs are minimised and that reliability and timeliness are guaranteed.

In the paper of (Holguin-Veras et al., 2011), it was advised to make a clear distinction between the concept of FG and FTG. Freight generation is a measure of the generation of demand determined by economics of production and consumption and this is found to be strongly-correlated with the firm's physical or operational characteristics. Using regression models, ordinary least squares method and cross classification, it was shown that commodity type, industry segment and employment are strong predictors for freight generation (Bastida and Holguin-Veras, 2009).

On the other hand, FTG is a measure of generation of traffic and is a consequence of logistic decisions and depends on inventory and transportation costs (Holguin-Veras et al., 2011). Traditionally, it has been accepted that a linear or a logarithmic function relates the independent variables, size of the store and number of employees, with FTG rates as the dependent variable. However, several studies have negated this conclusion and have shown that FTG has weak connection with size of firms and number of employees (McCormack, 2010, Iding et al., 2002, Shin and Kawamura, 2005b, Shin, 2005, Shin and Kawamura, 2005a).

## Freight Trip Distribution

The most common attempt to simulate the pattern of freight movement is through physical analogies such as the gravity model and entropy maximization (Wilson, 1970, Ortuzar and Willumsen, 2001). See Appendix A.1 for the detailed discussion and formulation of the gravity model.

## Modal split

In the aggregate level, modal choice treated using a binomial or multinomial logit formulation based on generalised costs. However, many factors need to be taken into consideration in the decision-making process choosing the mode of transport other than the operational costs and time such as geographical location and available service for the O-D pair, size and volume of consignments, amongst others. Aggregated models outputs the market share of a mode instead of the tonnes of commodity transported or the number of vehicles utilised.

A strategy to improve overall energy efficiency and reduce emissions by moving some goods  $p$  from mode A to a mode B, relies on key assumptions (Healey, 2009):

a) That  $p$  is technically contestable, i.e. both modes A and B are inherently suited to move  $p$ .

b) That  $p$  is commercially contestable, i.e. both modes A and B meet customer requirements and are cost-competitive for moving  $p$ .

c) That the actual energy use and emissions of mode B for shipping  $p$  is less than that of mode A.

## **Trip Assignment**

Trip assignment involves selecting the “best” route from a given origin to a destination for a given mode. This step should consider the type of goods carried, the vehicle chosen, the objective (minimise time, cost or maximise reliability) and whether the distribution is inter-urban or a long-haul inter-regional movement. Here, the route chosen is the one with the minimum impedance such as distance, time or monetary cost.

### **2.3.2 Modelling Urban Freight**

Urban freight movements are of particular importance because of the impact they cause on traffic congestion and safety to other motorists. When using the 4-step modelling approach for urban freight, the modal choice step is trivial as the typical available mode is only via trucking or road. However, the main difficulty faced by modellers with movements of goods in the urban setting is the difficulty of obtaining a reliable data for a trip generation model. In the case of passenger transport, commuters are usually willing to provide origin-destination information for administration-conducted surveys, but transport companies operating in a highly-competitive environment are normally more reluctant to provide commercially-sensitive data on shipments, tours or timetables (Morris et al., 1998b).

The “GoodTrip model” is a commodity-based, disaggregate approach that estimates urban goods distribution in the supply chain where the volume of goods arriving to each zone is estimated using consumer demand and then combined in flows for each type of good which are then assigned to vehicle trips (Boerkamps et al., 2000).

Meanwhile, (Munuzuri et al., 2010) developed a trip-based model using only limited data to estimate the number of delivery vehicles entering and leaving each zone in the city. It also uses an entropy maximisation approach to determine the trip distribution and the O-D matrix.

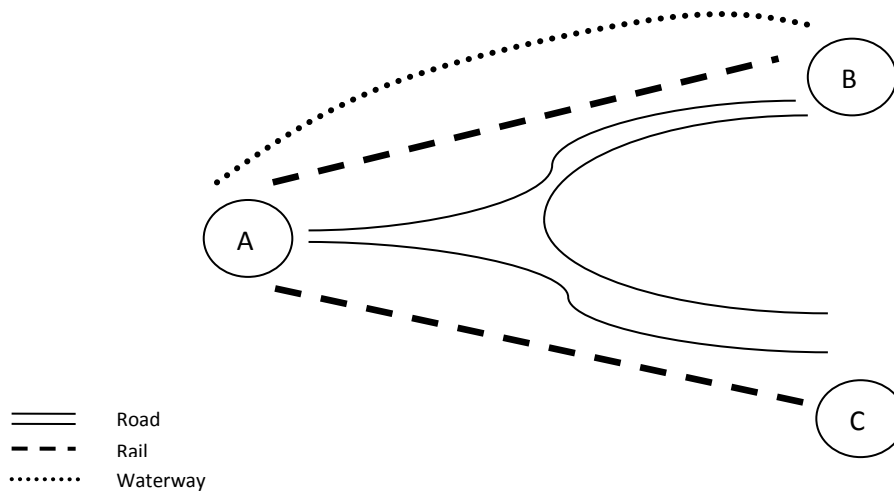
The work of (Holguin-Veras, 2000) discusses a comprehensive modelling approach that jointly considers commodity flows and vehicle counts. It incorporates logistic information and trip chaining behaviours, or alternatively trip length distribution. In this research, we would be tackling the last mile delivery link between the hub and spoke distribution system in the context of urban freight systems (Morris et al., 1998a) .

## **2.4 Mathematical Models**

### **2.4.1 Mathematical Representation of Multimodal Freight Network**

In its simplest sense, a network  $N$  is a set of points, called nodes and a set of point connectors called arcs. Consumer demand for commodities generate link flows on the network. If the physical network infrastructure represented by the network model supports transportation of different of different commodities by several modes then the result is a Multimodal Freight Network. A mode  $M$  is a means of transportation and represents a particular transportation service, an aggregation of several carrier networks, or specific transportation infrastructures (such as highways, railways and shipping waterways) with specific characteristics, such as vehicle type and capacity, as well as different costs or deterrence function assigned to that mode.

The base network is the network that consists of the nodes, arcs and modes that represent all the physical movements possible on the available infrastructure. The multimodal network is represented by a graph  $G = (N, L, M)$  composed of all the nodes  $N$ , arcs or links  $L$ , and modes  $M$ . Each link is represented by a triplet  $(i, j, m)$  where  $i, j \in N, m \in M$ .



**Figure 2.4.1 : Multimodal transportation network**

Consider a simple example of three cities denoted by  $A$ ,  $B$  and  $C$  such that the link  $(A, B)$  has all the modes permitted, link  $(A, C)$  has only the road and rail, while  $(B, C)$  has only the road mode. Each link is defined as a triplet  $(origin, destination, mode)$ . See Figure 2.4.1. Using this notation we have the following set of links for this example:

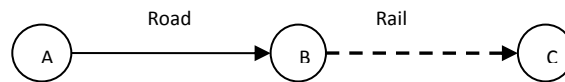
$$\{l_1 = (A, B, road), l_2 = (A, B, rail), l_3 = (A, B, waterway),$$

$$l_4 = (A, C, road), l_5 = (A, C, rail), l_6 = (B, C, road)\}$$



### 2.4.2 From Multimodal to Intermodal:

An intermodal freight network is defined as an integrated freight transportation system consisting of two or more modes providing efficient and seamless transport of goods from a given origin to a destination, which means a multimodal network  $(N, L, M)$  including corresponding transfer facilities  $T$ . These transfer facilities will have costs and delays associated for mode transfers at certain nodes of the network. Transfers are represented implicitly by a pair of links, one reaching the node and the other leaving the node. Transfer movements that are permitted at a node may then be addressed, displayed or listed by referring only to the pairs of links defining the transfer at the node.



**Figure 2.4.2 : Diagram of a transfer facility**

In the Figure 2.4.2, there is one transfer facility  $t$  given by  $t_1 = (A, B)(B, C)$ .

Note that mode to mode transfers may be restricted to occur only at specific nodes of the network and only between specific modes.

In the context of strategic planning of freight flows in an interregional scale, the most efficient use of transportation infrastructure is to transport the freight at least total (generalised) cost, which usually includes variables such as time and operational costs.

Components of the full costs of given intermodal network include the following : a) transport (internal) cost, b) time cost, c) handling cost, d) external costs (Janic, 2007).

However, a functional intermodal freight network country requires investments to build new infrastructures and maintain existing ones and that the true costs of each transportation mode is factored into the model including capital expenditures, time, maintenance, congestion and also pollution-related costs (Bolland, 2010, Black, 2010), as well as energy-related costs in the context of constraints on fuel supply. We will include this as new capacity constraints on the formulation in a separate section.

In mathematical terms, an intermodal freight network is represented by

$$(N, L, M, T)$$

where

$N$  - set of nodes

$L \subset N \times N \times M$  - set of links

$M$  – set of modes

$T \subset L \times L$  - set of transfers

Denote the cardinality of each of this set by  $n_N, n_L, n_M, n_T$ . For each link  $l \in L$ , a cost function  $c_l(\cdot)$  is associated which is dependent on the volume of goods on  $l$ . Similarly, a cost function  $c_t(\cdot)$  is associated with each transfer  $t \in T$ . In graphical terms, the cost function  $c_l(\cdot)$  is viewed as the length of the arc or link  $l$ . In contrast, the transfer point  $t$  is a node has no graphical interpretation of  $c_t(\cdot)$ .

The commodities or products transported over the network are denoted by  $p \in P$ , where  $P$  is the set of all products considered, which is of cardinality  $n_p$ . Each product  $p$  is shipped from origins  $o \in O \subseteq N$  to destinations  $d \in D \subseteq N$ . The demand for each product for all origin/destination (O/D) pairs is specified by a set of O/D matrices and may be solve by the gravity model or linear programming formulation.

The flow of product  $p$  on the intermodal network is denoted by  $v^p$  and consists of the induced flows of this product on links and transfers:

$$v^p = \begin{pmatrix} (v_l^p), & l \in L \\ (v_t^p), & t \in T \end{pmatrix}.$$

The flow of all the products on the network is denoted by:

$$v = (v^p), \quad p \in P$$

This  $v$  is a vector of dimension  $n_p(n_L + n_T)$ .

The average cost functions  $c_l^p(v)$  on links and  $c_t^p(v)$  on transfers correspond to a given flow vector  $v$ . Likewise the average cost functions for product  $p$  use analogous notations:

$$c^p = \begin{pmatrix} (c_l^p), & l \in L \\ (c_t^p), & t \in T \end{pmatrix}.$$

and

$$c = (c^p), \quad p \in P$$

This  $s$  is a vector of dimension  $n_p(n_L + n_T)$ .

The total cost of the flow on link  $l, l \in L$ , for product  $p, p \in P$ , is the product of the cost of transporting the product and the volume of product transported, that is

$$c_l^p(v) \cdot v_l^p.$$

Similarly, the total cost of flow on transfer  $t, t \in T$  is

$$c_t^p(v) \cdot v_t^p.$$

The total cost of the flows of all products over the intermodal network is the function  $Z$ :

$$Z(v) = \sum_{p \in P} \left( \sum_{l \in L} c_l^p(v) \cdot v_l^p + \sum_{t \in T} c_t^p(v) \cdot v_t^p \right)$$

The linear programming formulation of this transportation problem is given by:

$$\min Z(v)$$

subject to

$$0 \leq \Phi_l^p \leq v_l^p \leq \Psi_l^p, \quad p \in P, \quad \text{for all } l \in L$$

$$0 \leq \Phi_t^p \leq v_t^p \leq \Psi_t^p, \quad p \in P, \quad \text{for all } t \in T$$

Where  $\Phi_l^p$  and  $\Phi_t^p$  are the lower bounds for volumes that can transported on link  $l$  and transfer  $t$ , respectively, and  $\Psi_l^p$  and  $\Psi_t^p$  are the upper bounds for volumes to can transported on link  $l$  and transfer  $t$ , respectively.

In its compact, the problem is given by:

$$\min Z(v), \text{ subject to } v \in \Omega$$



The shortest path algorithm will be utilized in solving the optimal routes in the intermodal networks given the imposed objective function on minimizing the cost of traversing the links. Its mathematical formulation is as follows:

In the Figure 2.4.3, suppose 1 unit of product  $p$  is to be sent from A to B. As discussed in the network representation, each link  $l$  in the network is represented by a triplet  $(i, j, m)$  where  $i, j \in N, m \in M$  and the “cost” of flow on this link is determined by the volume of the flow, the distance between  $i$  to  $j$  and the mode of transport  $m$ . The goal is to find the shortest path from A to B which could denote minimum time, minimum cost (monetary) or maximum reliability, all of which are specified as cost attributes of the links. Likewise, transfer penalties are also imposed and accounted for in the total costs.

Computationally, finding the shortest path from an origin to multiple destinations is equivalent to determining the shortest path from an origin to a single destination (Ravindran, 2009). Dijkstra’s algorithm is a widely used, simple-to-implement algorithm that solves shortest path problems (Guelat et al., 1990).

See Appendix A.2 for the description of the Shortest Path Algorithm Formulation with transfers.

#### **2.4.4 Vehicle Routing Problem**

The Vehicle Routing Problem or VRP is an NP-complete combinatorial problem that finds the design optimal delivery from one or several depots to service a number of geographically scattered customers with a fleet of vehicles. An equivalent formulation of the VRP is to find the optimal collection routes from the customers and deliver to the

depots. The objective is to minimise the total cost of distributing or collecting the goods (Laporte, 1992, Christofides et al., 1981).

The basic formulation of general VRP is defined as follows:

Let  $G = (N, L)$  be a graph where  $N = [x_1, \dots, x_n]$  is a set of nodes representing the customers with the depot located at node  $x_1$ , and  $L$  is the set of links. For every link  $l_{ij}(i, j)$  with  $i \neq j$ , the cost of transport from  $i$  to  $j$  denoted by  $c_{ij} \geq 0$ . Assume  $M = [v_1, \dots, v_m]$  is a set of vehicles originating at the depot with capacities  $Q = [q_1, \dots, q_m]$ . The VRP is finding the least-cost vehicle routes design such that:

- a) Each customer  $V \setminus x_1$  is visited exactly once by one vehicle;
- b) All vehicle routes start and end at the depot.

To solve this problem practically, meta-heuristic methods such as tabu search of origin-destinations of shortest path costs are used instead of finding exact solutions (ESRI, 2012). The reason for which is that the largest size of general case VRPs reported solved in literature is only for  $n = 10$  or  $12$  (Eilon et al., 1971). See Appendix A.3 for the full mathematical formulation of VRP.

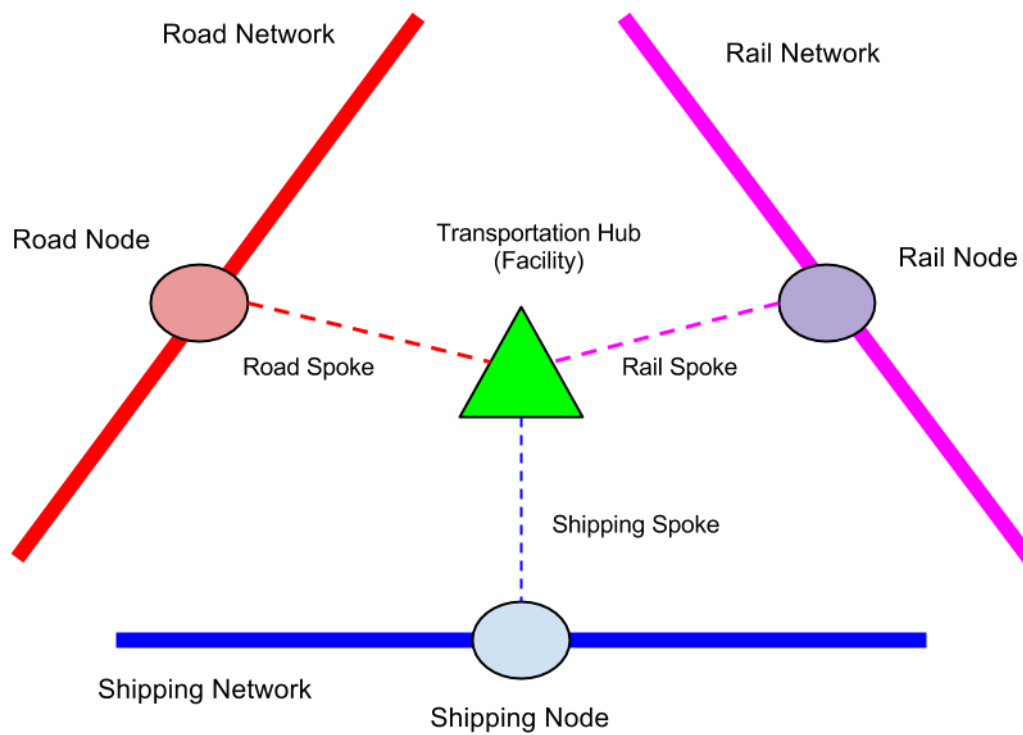




*Intermodal Freight Network'* or (GIFT) using ArcGIS 9.3 to create an intermodal network model connecting highway, rail, and shipping networks through ports, rail yards and other transfer facilities in the United States and Canada (Winebreak et al, 2008). The main distinction of the GIFT model from other GIS-based models is the inclusion of energy and environmental attributes on each segment of the intermodal network. Energy costs are measured as British thermal unit per Twenty-foot-equivalent unit-mile travelled or (BTU/TEU-mi). The emission attribute is measured in terms of different pollutants (grams/TEU-mi) including carbon dioxide [CO<sub>2</sub>], carbon monoxide [CO], particulate matter [PM<sub>10</sub>], nitrogen oxides [NO<sub>x</sub>], and sulphur oxides [SO<sub>x</sub>] (Winebreak 2008, Comer et al 2010).

The GIFT model uses a hub-and-spoke approach in order to form a connection between the three modal networks (Figure 2.5.1). Network segments refer to actual and existing network datasets in the United States and Canada. Network spokes are artificial connections created to connect the 3 modal networks and represent transfer facilities. The hub-and-spoke approach connects modes directly through facilities using a Python-based ArcGIS script that builds an artificial link between appropriate modal networks and transfer facilities. These spokes are artificial because they may not follow a physical connection (such as a road) but instead are used as proxy for transfer paths.

To make a realistic scenario, transfer penalties are applied to all of the spokes to represent costs, energy use, time delays, and emissions associated with intermodal transfers. These penalties are integrated into the overall optimisation calculations so that they are incorporated in route determination. As with any other GIS-based model, GIFT's analytical techniques utilised the shortest path algorithm.



**Figure 2.5.1 : The Hub-and-Spoke approach in the GIFT model**

## **2.6 The Last Mile**

The last leg of the supply chain or commonly referred to as the 'last mile' usually occurs in the urban setting possibly in the central business districts (Scott, 2009). These are the environments which retail consumers have accessed to. For this reason, freight mobility is a crucial issue with widespread congestion, inadequate space for docking and parking and theft and vandalism in this environment (Morris et al., 1998a).

As the links of the supply chain get closer to the final customer, large scale consolidated deliveries are more difficult to apply and as a result the last mile setting is that it is of unimodal nature, which is a major limitation. Freight deliveries are conducted by less than full truck loads as a result of the demands of the retail sector requiring lower volumes and higher frequencies of deliveries (Rodrigue et al., 2006). At the same time competition within the transport and logistics sector caused pressure to meet narrow time delivery windows and increase individualised deliveries to business, which in turn forces the vehicles to run near half their capacities (Allen, 2011).

In general, there is a negative sentiment against trucks in urban areas. They are considered as major hazards to the safety of other motorists, pedestrians and residents and probably seen as the main cause of traffic congestion and pollution. At the same time, their size and tonnage carried produce significant strain to the road network necessitating more frequent maintenance. However, trucks delivering to urban areas are the lifeblood of the retail sector.

In (McKinnon, 2006a) , an assessment of the impact of a temporary disruption of road freight transport on the United Kingdom's economy and specifically investigated the effects on the grocery retail sector, catering, fuel supply, healthcare, banking, postal services,

parcels, beer and waste disposal. The conclusion is that the level of activity would drop sharply in a few days following the withdrawal of transport.

The last mile is often the most complex and convoluted element of the chain to organise as it reconciles many customers, a variety of shipments and reliability difficulties related to urban congestion and pedestrian safety. As a result, the last mile freight mobility is constrained by city ordinance laws.

One way to understand the last leg of retail supply chain is to examine the truck trip patterns and rates delivering to the stores and what factors or parameters influenced these deliveries. The hypothesis is that the size of the retail establishment will have a direct correlation with the number of trucks needed to replenish its supply. It has been accepted that a linear or a logarithmic function relates the independent variables such as size of the store and number of employees, with TTG rates as the dependent variable. However, the study of (McCormack, 2010) on 8 grocery stores in Puget Sound Washington found that an increase in the store's floor area by 5000 ft<sup>2</sup> (465 m<sup>2</sup>) would reduce the total number of trucks by one. The study used correlation analyses and the size of the facilities ranged from 23,000 ft<sup>2</sup> to 53,000 ft<sup>2</sup> (2137 m<sup>2</sup> – 4924 m<sup>2</sup>).

There are 2 possible explanations for this phenomenon. Firstly, larger stores will probably have a regional warehouse or distribution centre which would eventually lead to lower truck trip rates as the centre consolidates freight volumes for its chain of stores. Secondly, smaller stores will have smaller storage capacity necessitating more frequent deliveries. In addition, stores with more direct service deliveries and lower distribution warehouse deliveries may also generate more truck trips because Direct Store Deliveries (DSD) trucks

tend to be smaller and involve food categories with higher volumes such as soda, bread and milk.

Operations research algorithms also have the potential to address the logistics of the last mile and at present platforms are being developed and improved to provide sustainable solutions for freight deliveries to urban areas (Morris et al., 1998a, Morris et al., 1998b, Finnegan et al., 2005). In particular, one interesting problem is to decrease the empty running of return trips of the trucks by sophisticated freight consolidation methods, vehicle routing and scheduling requiring collaborated efforts between shippers, manufacturers and retailers (McKinnon, 1996, McKinnon, 2006b).

## **2.7 Local Food Systems**

Local food systems have recently gained popularity due to the perceived high-quality and organic local produced, support for fair-trade policies, as well as serving as a pillar of community-building. This notion is called “social embeddedness” which lies on trust, social relations and exchange between the producers and consumers is an important facet of a sustainable economic paradigm (Oosterveer and Sonner, 2012).

In particular, the recent interest in local food is the belief that the shorter distances travelled by the products as well as the removal of some links on the supply chain such as processing and packaging has lesser impact to the environment and also less reliant on fossil fuels.

One measure associated with local food systems is direct marketing which aims to simplify the complex and convoluted stages in the supply chain of the conventional food systems. The Farmers' market is the most familiar form of direct food marketing.

### **2.7.1 Life Cycle Assessment and Food Miles Studies**

The standard and most widely use method to assess energy consumption in the food supply chains is through Life Cycle Assessment (LCA) (Pelletier et al., 2011). In the analysis, the energy consumed and environmental impacts by the product in each stage in the supply chain, from cradle to the grave, is measured. However, one problem with LCA is that the total supply chain range of processes to be included in the assessment is too numerous and with their analyses, errors accrued with the estimations of inexact values (Browne et al., 2005, Browne and Allen, 2004). Moreover, there is need for standardisation of the methodologies to achieve better consistency and comparability of energy analyses (Pelletier et al., 2011). LCA also encompasses an assessment of environmental harmful effects over longer periods of time including pollution from constructions which could take years to evaluate (Kim and Bee, 2011).

Another common approach in the use of LCA is to contrast the balance of energy consumption between production and transport processes. The analysis of the latter in agricultural chains is often termed as the 'food miles' assessment.

The study of Pirog et. al compared the food miles for the local, Iowa-based region and the conventional/national system by examining distances from producers to food retailers. It found that the conventional system used 4 to 17 times more fuel than the regional and

local systems (Pirog et al., 2001). A Montana-based study yielded similar results with higher fuel consumption and carbon dioxide emissions for food purchased at the conventional supermarket systems and also emphasised the lack of transparency of the actual products origins (Spielman, 2007). Likewise, a partial LCA assessment including transport from production to the sales point, product storage, warehouse and shop maintenance, and employee travel and customers' transport have showed that local food systems have similar energy efficiency to supermarkets. Moreover, they concluded that there is room for substantial improvements in the local food system through the development of urban food basket system (Mundler and Rumpus, 2012).

On the other hand, several studies have invalidated the result that food that travelled lower food miles or those sourced locally are less energy-intensive and carbon footprint than their global counterparts. Results of the comparison of environmental impact of different types of food such as meat, fish, milk and dairy, grains, vegetables, sugar and oils, showed that the agricultural production stage is the largest contributor to the life cycle impact compared with transport and processing stages (Mogensen et al., 2009).

A comprehensive research by C. Saunders (Saunders et al., 2006) revealed that dairy, lamb, apples and onions produced in New Zealand and shipped to the United Kingdom (UK) have smaller energy usage and carbon footprints than the equivalent products produced in the United Kingdom. To be precise, dairy from the UK uses twice as much energy per tonne of milk solids than New Zealand's dairy; lamb locally produced in the UK is four times higher than energy used by New Zealand's lamb producers; while the energy costs of New Zealand apples shipped to the UK are approximately 60% of those grown in the UK; and finally UK onions have energy costs which are 30% higher than those shipped from New Zealand. All

of these results already accounts for the energy used in transport. The study of E. Schlich in (Schlich and Fleissner, 2005) derived an analogous conclusion showing that lamb produced in New Zealand is more energy efficient than those in Germany, even when taking into account the transport costs.

Meanwhile, research results of Van Hauwermeiren et. al in Belgium showed that local food systems actually use slightly more energy than the conventional supermarket system. The study simulates one full summer season using data from interviews with suppliers of food and accounts for the total energy used for transport, processing and storage (Van Hauwermeiren et al., 2007).

### **2.7.2 The Potential of Local Food Systems**

The preceding section showed that there are two schools of thought regarding local food systems. One argues that the reduction of distances travelled by food yields lower energy consumption, while others maintained that freight transport energy accounts for much less of the total energy when agricultural production is considered.

The initial claim on food miles may in fact be too simplistic as transport energy depends not on the travelled distance but also on the chosen transport mode, fuel efficiency of vehicles and vehicle utilization. For instance, considering energy intensity on a tonne-kilometre bases, cargo ships are about as 1.5 times as efficient as rail and more than 10 times as efficient as trucks (Pelletier et al., 2011). Taking into account the potential savings in using intermodal networks, overseas shipping of agricultural products may indeed render the local food systems as less-energy efficient.



Nevertheless, we do not like to discount the possibility of improving the energy efficiency of local food systems. The conventional systems' paradigm works effectively at the moment but they are still subject to risks in the global supply chain.

One famous example of a shift from the conventional wide-sourcing system to more local production is that of Cuba in the 1990s, when collapse of the supply chain from the former Union of Soviet Socialist Republics or USSR caused drastic shortfalls in fuel and agro-chemical input supplies from the United States. This occurred over a very short period of time and resulted in severe food crisis (Wright, 2009). Cuba's transition to a local and self-reliant agricultural model may serve as a model for the post-peak oil era.

## **2.8 Customer Access**

Commodity flows in the supply chains usually create a dichotomy between the products and the consumers. However, production and consumption are not mutually exclusive components of the supply chain but instead are intrinsically interdependent and interconnected with each other through forward and feedback links (Spielman, 2007). There are many facets of this interplay between producers and consumers.

Firstly, consumers growing perception of organic and local products have led to popularisation of the concept of food miles and carbon accounting which have been driving forces of sustainable food distribution, retailing and accessibility. At the same time, more companies are recognising this trend hence orienting their marketing and production to reflect eco-awareness and greener logistics.

However, the aspect of producer and consumer dynamics in the supply chain which we would like to address in this thesis is the access of customers to the marketplace, whether in the traditional supermarket or local food system setting. A famous research result showed that customer shopping trips may consume more energy than the entire supply chain, even when production is included (Browne et al., 2008). Given that customers have no other alternative modes of access to stores but through the use of private vehicles, the results of the above-mentioned study is unsettling and further adds to the motivation of including customer accessibility to stores in freight transport.

The transport energy for households is strongly influenced by the design and layout of the built environments in the given urban form which is explained in detail by numerous researches (Cao et al., 2009, Chatman, 2005, Handy et al., 2005, Bento et al., 2003). Built environments are defined as land, buildings and transportation infrastructure. However, the focus of this thesis would be on the dynamic interrelationship between freight transport and logistics strategies with personal transport. For instance, the centralisation of food production and trade in supermarkets has been shown to increase dependence on private vehicles when buying food (Wallgren and Hojer, 2009).

A critique by Mariola on the superficial resilience of local food systems pointed out that customers passionate about the environment are driving to the local food stores to purchase their goods (Mariola, 2008). The results of the study conducted by Coley et. al in the United Kingdom suggest that if a consumer drives a round-trip distance of more than 6.7 km in order to purchase organic vegetables, their carbon emissions (which is a direct factor of energy consumption) are likely to be greater than the emissions from the system of cold storage, packing, transport to a regional hub and final transport to customers used

by large-scale vegetable suppliers (Coley et al., 2009). As Rendall mentioned in his dissertation, personal transport is the most discretionary link in the whole supply chain where the most fuel reduction could take place (Rendall, 2012).

Local shopping may reduce automobile dependence as it encourages the use of active modes such as walking or biking. Meanwhile, the geographical location of the store is cited as the primary reason for not shopping at Farmers' market (Lockeretz, 1986, Eastwood et al., 1999). Geographical distance together with the built environments are factors for shoppers to walk to the stores (Handy and Clifton, 2001, Jiao et al., 2011) .

## **2.9 Constrained System**

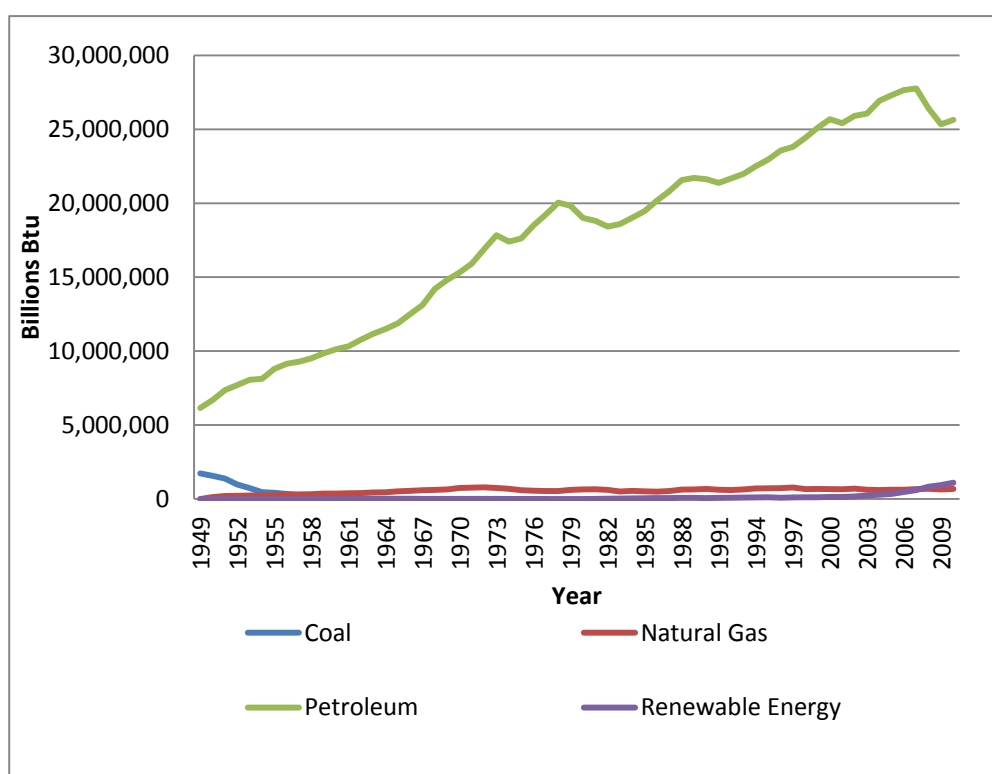
This section will help provide the information needed in the formulation of the model for constrained freight transport and logistics systems. In order to provide the analytical tools for future scenarios brought about by diminishing fuel supply and tighter restrictions on emissions, we provide actual statistics documented by well-established and credible sources.

### **2.9.1 Demand-side aspect of the system**

As mentioned in the motivational statement of this research, there are two schools of thought used to address the issue of peak oil and climate change scenarios for Transport and Logistics namely a) using alternative energy sources and b) demand reduction (Sorell et al., 2009). There is an array of potential substitute fuels such as natural gas, ethanol and methanol as well as electric, solar and hydrogen, but both the direct costs and indirect costs associated with its required technology renders them currently uneconomical for large-scale use (Aftabuzzaman and Mazloumi, 2011). Because the first option is an

inadequate measure at present, then placing emphasis on demand-side aspect is the *de facto* choice (Krumdieck and Dantas, 2008, Rendall et al., 2011).

According to the annual energy review of 2010 published by the U.S. Energy Information Administration, the transportation sector accounts for 28% of the total consumption. Petroleum accounts for 94% of the energy source while only 4% comes from renewables (EIA, 2011). The actual historical data is given in Figure 2.9.1.



**Figure 2.9.1 : Energy consumption estimate for the transportation sector**

Replacing the infrastructure, particularly transportation, that is based on oil with one based on renewables, will in itself require large amounts of energy. Even if renewables were able to make up all of the lost energy from oil, still more would be needed to afford any economic growth (Nelder, 2009).

In the current economic paradigm, changes in demand patterns are reflected in the following elements (Crainic and Laporte, 1997):

- a) **Volume** – The volume of goods necessary required for consumption in a given location is influenced by the demographic changes in the population. As more people live in the cities, fewer are living near production sites or farms, and thus necessitating higher volumes of food transported (Halweil, 2002).
- b) **Spatial distribution** – The spatial distribution of commodities are influenced by spatial characteristics of supply and demand sites. Communities may appear and grow or be abandoned, paving way to alterations in the economic profile of a country or a region as well as patterns of trade and freight flows.
- c) **Composition** – The relative importance of commodities between intraregional, inter-regional and international trading also influenced the commodity flow patterns. For instance, agricultural products which come from a specialised farmland with good soil vegetation and climate may be in high demand even from geographically distant places.

In a constraint system, population and demography still plays a key role in the changes in demand patterns, however so does energy supply and cap on allowable emissions. These constraints may bring about decrease in freight volumes; shorten the links on the supply chain via consumer's preference towards locally-produced goods. Finally, levels of essentiality of goods will also play a critical factor in shaping transport and logistics.

### 2.9.2 Outlook for the future

Delphi experts published 4-part report on how fuel supply and issues on climate change will reshape the Transport and Logistics Industry (Ruske and Kauschke, 2009, Ruske and Kauschke, 2010, Ruske and Kauschke, 2011). According to their report, *“supply chain design, including the location of production sites, will need to take into account energy and emissions in the logistics processes. There will be no reverse of globalization, but many supply networks will be established at the regional level.”*

The summary of important points is presented in Appendix B. The following hypotheses have direct implication and will be the basis of the hypothesis of our research which are constraints on fuel and emissions (Ruske and Kauschke, 2009, Ruske and Kauschke, 2010):

- That ‘the oil price has risen to \$1000 per barrel as a result of peak oil production decades ago’ has 27% chance of occurrence. Even if the consensus clearly disagrees with this proposition, the panel showed a high level of uncertainty about oil resources, usage and price developments.
- That ‘alternative energy sources accounts for more 80% of the total’ has 52% chance of occurrence.
- That ‘locally produced goods are given high preference by consumers’ has 60% chance of occurrence.
- That ‘larger trucks will be utilised much more to compensate for rising transportation costs’ has 60% chance of occurrence.
- That ‘the issue of modal shift to rail and shipping is obsolete’ has 50% chance of occurrence.

- That 'minimisation of energy consumption is the paramount criterion in supply chain design, rather than cost efficiency and speed' has 55% chance of occurrence.
- That 'transport infrastructure development strongly focuses on urban areas, while rural areas are neglected' has 68% chance of occurrence.

Using consensus amongst transport and logistics sectors' industry experts as well as academicians and politicians, the conclusion is that oil price will be a key parameter affecting the industry and will unlikely to change in the future but instead its impact will increase as supply diminishes. Consumers will also be main stakeholders in this issue as their behaviour has significant impact on the sector and a shift towards more sustainable thinking could render the current global supply networks on a local or regional level.

The most probable extreme scenario would be that competition to deliver quickly and cheaply such as 'Just-in-time' processes will be updated and that transport and logistics companies recognise that cheap and quick deliveries do not reflect value for customers any longer. Global procurement, production and distribution of products will continue to exist but only if they can be achieved in a sustainable manner (Ruske and Kauschke, 2009). In addition to the issue of fuel supply, another important factor will be regulation such as the emissions trading system.

In line with the Delphi comprehensive study is the 2008 World Energy Outlook publication of International Energy Agency (IEA). It describes the impending challenges that will transform the landscape of the transport and logistics sector. This marks the first time that IEA who always maintain a bullish stance on peak-oil, seeing it as an opportunity rather than a crisis, acknowledged that the *"worlds' energy system is at a crossroad in supplying the world's growing energy needs that does not irreparably harm the environment,"* and

calls for *“the urgent need for a veritable energy revolution”* (International Energy Agency, 2008).

### **2.9.3 Emissions as a Constraint**

For most of our discussion, we have denoted emissions to be in conjunction with energy supply issues, perhaps rendering the former as a trivial element of the post-peak oil dilemma. This is expected as fuel and emissions are usually dealt with collectively since burning of fossil fuels result in greenhouse gases.

However, we would like to stress out that even though energy scarcity and low-carbon objectives are frequently grouped together, the issue of reduction of emissions is not just a stand-alone concept but its significance as a constraint in the freight transport and production system may actually be the critical factor and the bigger agenda in the system overhaul (Ruske and Kauschke, 2009, International Energy Agency, 2008).

The European Union Emission Trading Scheme (EU ETS) is the first and largest emissions trading scheme in the world launched in 2005 to tackle the issue of climate change. It works on a ‘cap and trade’ principle where in a cap or limit is set on the total amount of greenhouse gases are allowed to be emitted on factories, power plans and installations in the system. The cap is reduced after each trading period lasting for several years; the second scheme coincides with the commitment period of the Kyoto Protocol from January 2008 to December 2012. By 2020, emissions from sectors under the EU ETS will be 21% lower than in 2005 (European Commission, 2013).

Globally, transportation accounts for more than 13% of CO<sub>2</sub> emissions with road transport tallying for 92.3% of the total (IPCC, 2007). Clearly, potential reductions and meeting the emissions limit may be attained through imposing a cap on the freight sector. As of present,



the only freight transport division included in EU ETS is the aviation industry, which represents only a small fraction of total freight volumes but is the most emission-intensive mode. A proposal to include road freight in the EU ETS and its feasibility scheme is studied by Jochem (Jochem, 2012).

Similarly, the New Zealand Emissions Trading Scheme (NZ ETS) is the country's commitment to meeting international obligations around climate change (Ministry for Environment, 2013a). Under this scheme, New Zealand pledged to reduce greenhouse gases to 5% below 1990 levels by 2020. An annual inventory report is prepared by the Ministry of the Environment on the removal of gases such as CO<sub>2</sub>, methane (CH<sub>4</sub>), nitrous oxide (N<sub>2</sub>O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF<sub>6</sub>). The percentage of change for each gas from 1990 to 2011 is shown in Table 2.9.1 (Ministry for Environment, 2013b).

Combustion, production and transport of fossil fuels contribute to CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O levels while the fluorinated gases are highly potent gases emitted from a variety of industrial processes (EPA, 2013). In 2011, road transport contributed 12,404.8 Gg (37.4 per cent) to total CO<sub>2</sub> emissions (Ministry for Environment, 2013b).

**Table 2.9.1: New Zealand's total gross emissions by gas in 1990 and 2011**

Greenhouse gas emissions	Gg – CO <sub>2</sub> Equivalent		Percentage of change
	1990	2011	
CO <sub>2</sub>	25,047.1	33,162.2	+32.4%
CH <sub>4</sub>	25,650.3	27,050.1	+5.5%

N <sub>2</sub> O	8,300.6	10,689.7	+28.8%
HFCs	N/A	1,885.1	N/A
PFCs	629.9	30.2	-95.2%
SF <sub>6</sub>	15.2	17.6	+15.9%
Total	59,643.1	72,834.9	+22.1%

## **Chapter 3: Freight Studies in New Zealand**

As in most countries, freight movement plays a vital role in sustaining and supporting economic developments in New Zealand and being geographically isolated also puts it a higher risk in both man-made and natural disruption in the global supply chain. The freight sector is estimated to consume about 43% of all energy used by the transport sector in New Zealand (Paling, 2008).

The country's economy is heavily oriented towards export of dairy and other agricultural products while being considerably dependent on oil imports and will remain so for the foreseeable future. Even though New Zealand has a domestic production of 55,000 barrels per day, it consumes 148,000 barrels per day (Smith, 2010). But even if domestic production can be harnessed to its full potential, it would still be paying the world price for oil, whether it is produced domestically or not. Hence the country would be affected both directly and indirectly via its trading partners by decrease in the world oil production and is at a high risk in terms of fuel crises.

### **3.1 Geospatial Data for New Zealand**

Most freight and freight-related studies in New Zealand utilized geospatial boundary information created and regularly updated by Statistics New Zealand (Cowell, 2010)

*Statistics New Zealand maintains an annual meshblock pattern for the collection and production of statistical data, allowing data to be compared over time. A meshblock is the smallest geographic unit used by Statistics New Zealand for which statistical data is collected and processed. A meshblock is defined by a geographic area, varying in size from a part of a city block to large areas of rural area. Each meshblock abuts against another to form a network covering all of New Zealand, including coasts and inlets and extending out to the 200 mile economic zone. Meshblocks area added to together to build up a larger geographic areas such as area units and urban areas. They are also the principal unit to draw and define electoral districts, territorial authorities (TA) and regional councils. Territorial authorities are the second tier of local government below regional councils.*

Likewise, our models and analyses would also use the mesh blocks, territorial authorities, and regional administrative regions together with other New Zealand geospatial data which will be matched to the given mesh block unit. See Appendix B for the meshblocks, territorial authority units and administrative regions map. As of 2012, there are now 46632 meshblocks, 67 territorial authorities and 16 regions in New Zealand. Depending on the scale necessary and suitable for the analysis, the appropriate geospatial dataset may be used.

### 3.2 National Freight Demands Study

In (Paling, 2008), a 17 key commodity classification system based on the specific industry's contribution to the freight sector is used to derive a commodity-based freight model for New Zealand. The individual commodity flows are estimated by identifying the total size of the market and if possible their regional distribution of activities. Three main modes are involved in the movement of goods in the country, road, rail and coastal shipping. The estimates of movement on a commodity-basis were combined and compared with information on total estimated freight flows built up from information on rail and coastal shipping movements and the estimated volume of road traffic derived from Road User Charges data (MOT, 2008b).

**Table 3.2.1 : Freight movements for selected commodity groups**

Selected Commodity Group	Tonnes Lifted	% of Total	Tonne-kms	% of Total
	(Millions)		(Billions)	
Milk & Dairy Products	21.0	13.8	1.9	10.6
Logs & Wood Products	30.3	19.8	3.8	21.1
Livestock & Meat	4.5	2.9	0.6	3.3
Horticulture	4.2	2.7	1.1	6.1
Aggregate	40.2	26.3	2.3	12.8
Coal	6.4	4.1	1.3	7.2
Petroleum	9.0	5.8	2.2	12.2
Limestone, Fertilizer,	18.8	12.3	1.6	8.9

Other metals & Minerals	3.9	2.5	0.5	2.8
Retail & Courier	14.5	9.5	2.9	16.1
Total	152.7	100	18.0	100

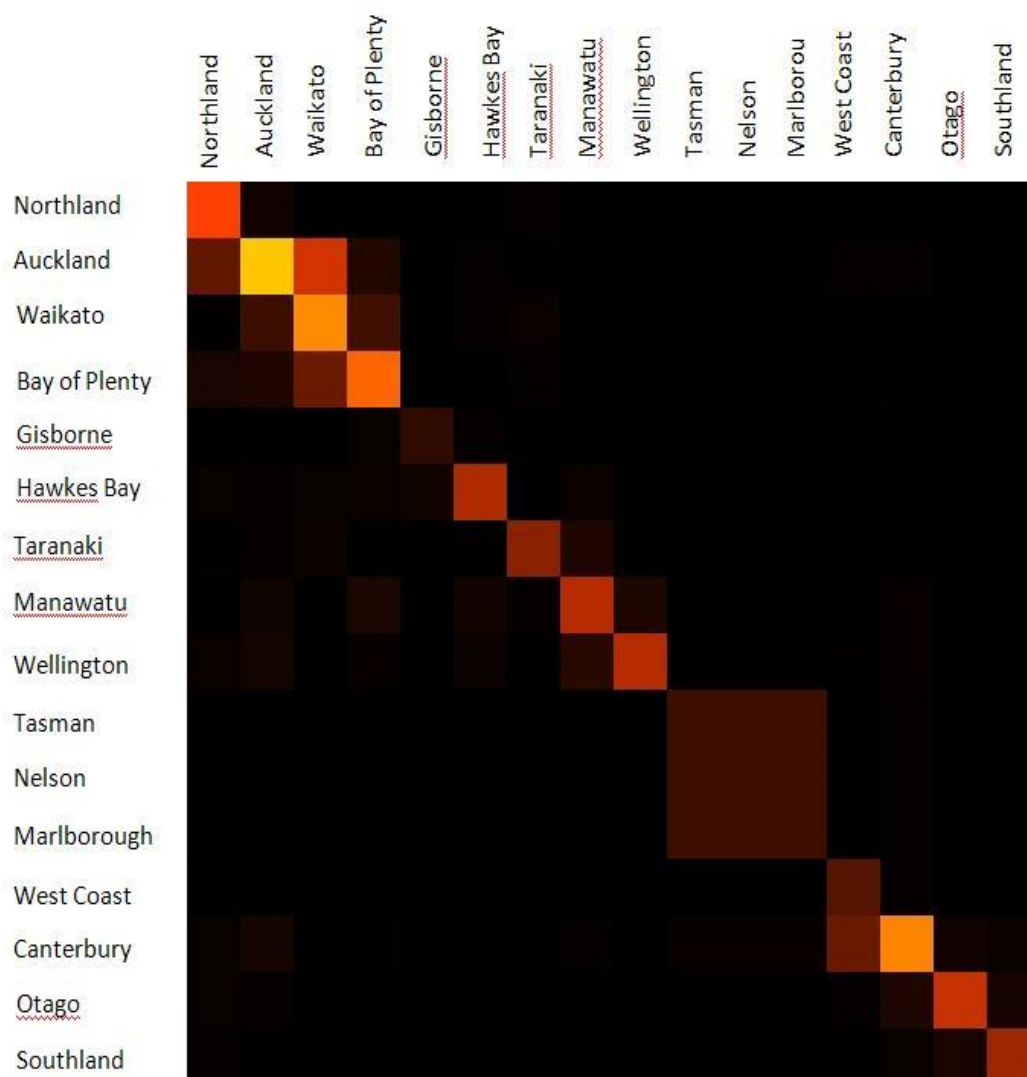
Total movements in terms of tonnages are dominated by aggregates, logs and wood and dairy products, which combined are estimated to account for about 60 percent of the total movements identified. However, for the tonne-km patterns, the share of aggregates and limestone are much smaller, reflecting the shorter distances travelled by these low-value commodities. The share for retail and couriers is much higher reflecting their nationwide distribution patterns.

New Zealand is divided into 16 regions namely Northland, Auckland, Waikato, Bay of Plenty, Gisborne, Hawkes Bay, Taranaki, Manawatu-Wanganui, Wellington, Tasman, Nelson, Marlborough, Westcoast, Canterbury, Otago, and Southland (see Appendix C.3). For each commodity, listed in Table 3.2.1, the linkages between the areas where goods are produced or imported and those where they are consumed and exported is also determined.

One way to look at the intra-regional and interregional flow patterns of all the commodities is to express the obtained total freight matrix in (Paling, 2008) or (Bolland, 2005) in terms of a 16×16 image matrix. The following image processing technique is conducted by the author using the data given in the above-mentioned reports. See Figure 3.2.1.

Each element of the matrix with a particular value corresponds to a single pixel and assigned a colour based on its value. For illustrative purposes, the pixels are expanded into a square block. The resulting image is a colour-heat map of freight movements for any given origin-destination pair where lighter blocks denote heavier flow of commodities than darker blocks.

Note that the blocks with the lightest colours are on the diagonal showing that most of the freight movements concentrated intra-regionally. For example, the majority of the commodity flows occur intra-regionally within the Auckland, Waikato and the Canterbury regions. The next most prevalent direction of freight flows are from regions closer to each other, which are represented by the sub-diagonal and super-diagonal matrix elements in the heat map. In this case, Auckland to Waikato and Canterbury to West Coast are the origin-destination pairs with the highest concentration of flows.



(From National Freight Demands Study, Richard Paling Consulting, 2008)

**Figure 3.2.1 : The final freight matrix expressed using a colour-map (Paling, 2008)**

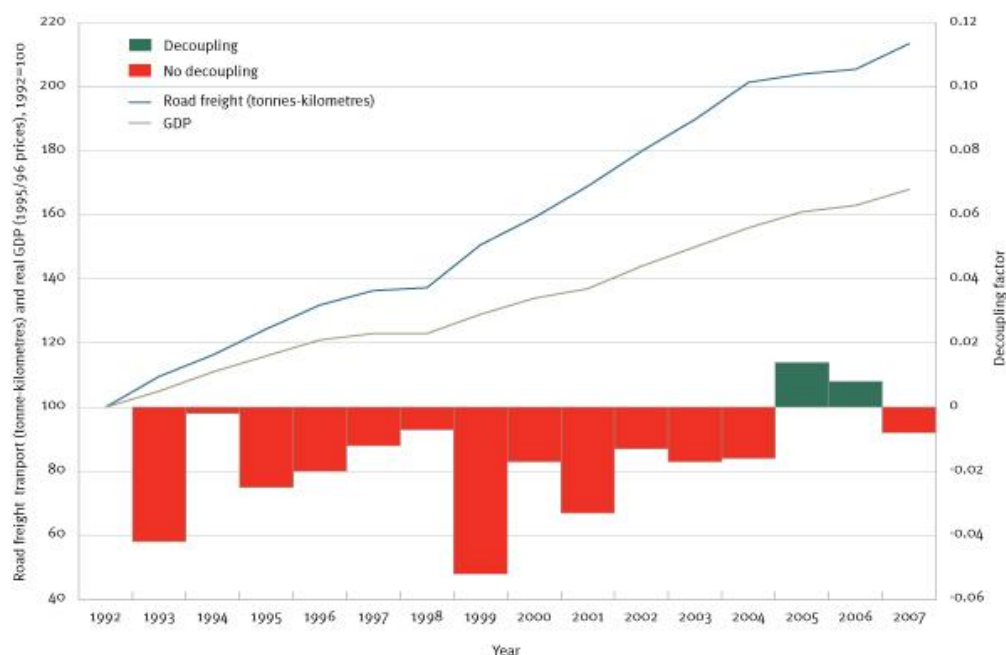
### 3.3 Freight Transportation Trends in New Zealand

In New Zealand, road freight movements play an essential role in sustaining and supporting economic growth and contribute to the quality of life of its residents. According to the New Zealand Business Council, freight volumes would increase by 70-75% over the next 30 years if the current growth rate continues (NZBC, 2011).



An increase in road freight is tied up to gross domestic product (GDP) growth. In fact, GDP has been used as a basis in forecasting road freight growth and serves as guidance or gauge for the public sector in transport-related construction projects.

However, decoupling of GDP and road freight, where GDP grows at a faster rate than road freight, is one of the holy grails in the field of the freight transportation (McKinnon, 2007). Unfortunately for New Zealand, trends have shown that road freight volumes increased faster than GDP growth, in particular between 1992 and 2007, decoupling was only manifested on years 2005 and 2006 (MFE, 2009).



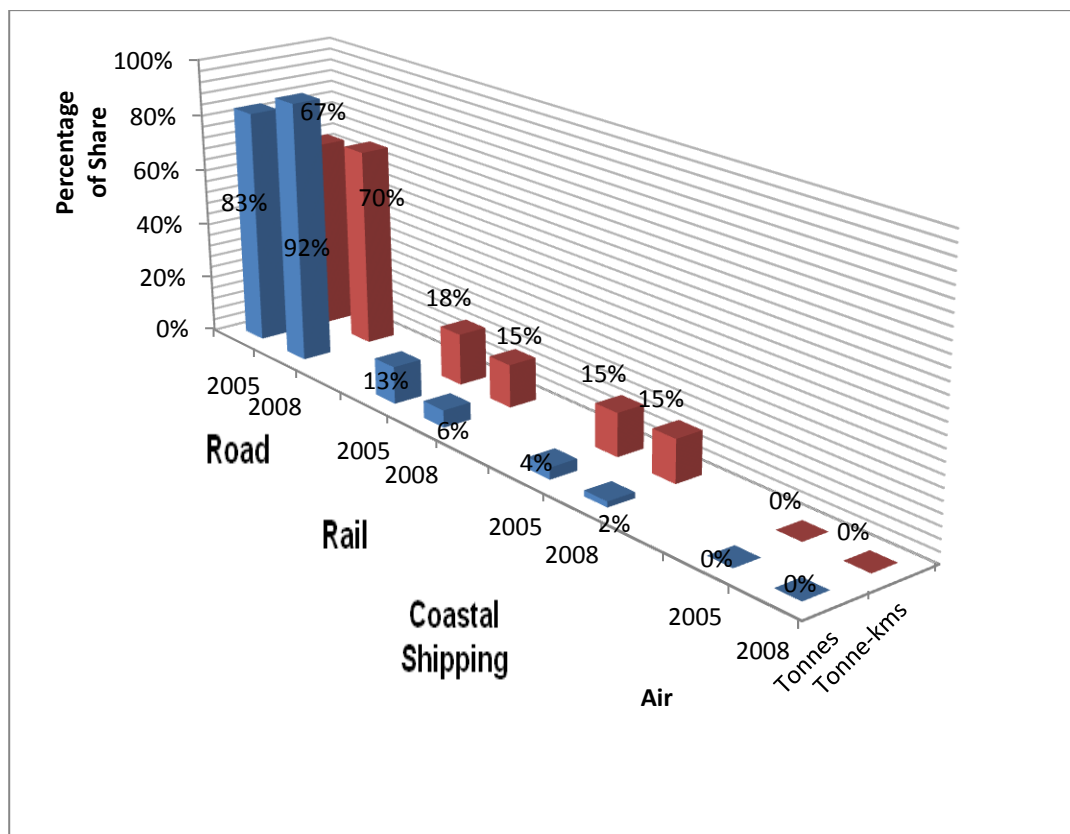
**Figure 3.3.1 : Decoupling trends in New Zealand (MFE, 2009)**

Decoupling is particularly important as it offers the prospect of economic prosperity with reduced impact on the environment in the form of emissions. At the same time, in light of peak oil, the sustainability of the over-reliance of New Zealand's economy on road freight is in question. One way to accomplish decoupling and to solve the over-reliance on fossil fuel

is a shift to less energy intensive and lower emission modes such as rail or coastal shipping (McKinnon and Woodburn, 1996).

The trends of increasing dependence and reliance on the road network of the freight movements in New Zealand is evident from the increase of road freight utilisation from years 2005 to 2008 (Bolland, 2005, Paling, 2008). The percentage share of the different freight modes including road, rail, coastal shipping and air is summarised in Figure 3.3.2. Expectedly, road freight has a bigger share for tonnes lifted than tonnes-kms travelled as rail and shipping are utilised more for longer distances, while air has negligible percentage owing to its high costs. Both tonnes lifted and tonne-kms travelled on the road increased from years 2005 and 2008 while rail and coastal shipping have slightly decreased.

The Canterbury region is shown to succeed in the implementation of best freight practice (Upton, 2008) but road still remains as the only viable option in most metropolitan areas. Coal, the largest flow of inter-regional freight movements already utilises the rail network.



**Figure 3.3.2 : Summary of freight task by mode for years 2005 and 2008**

The breakdown for selected commodities shows that modal shares vary significantly by products with rail having a relatively high share of coal, dairy products, and meat is shown in Figure 3.3.3. Coastal shipping only has significant share of commodities such as petroleum and cement.

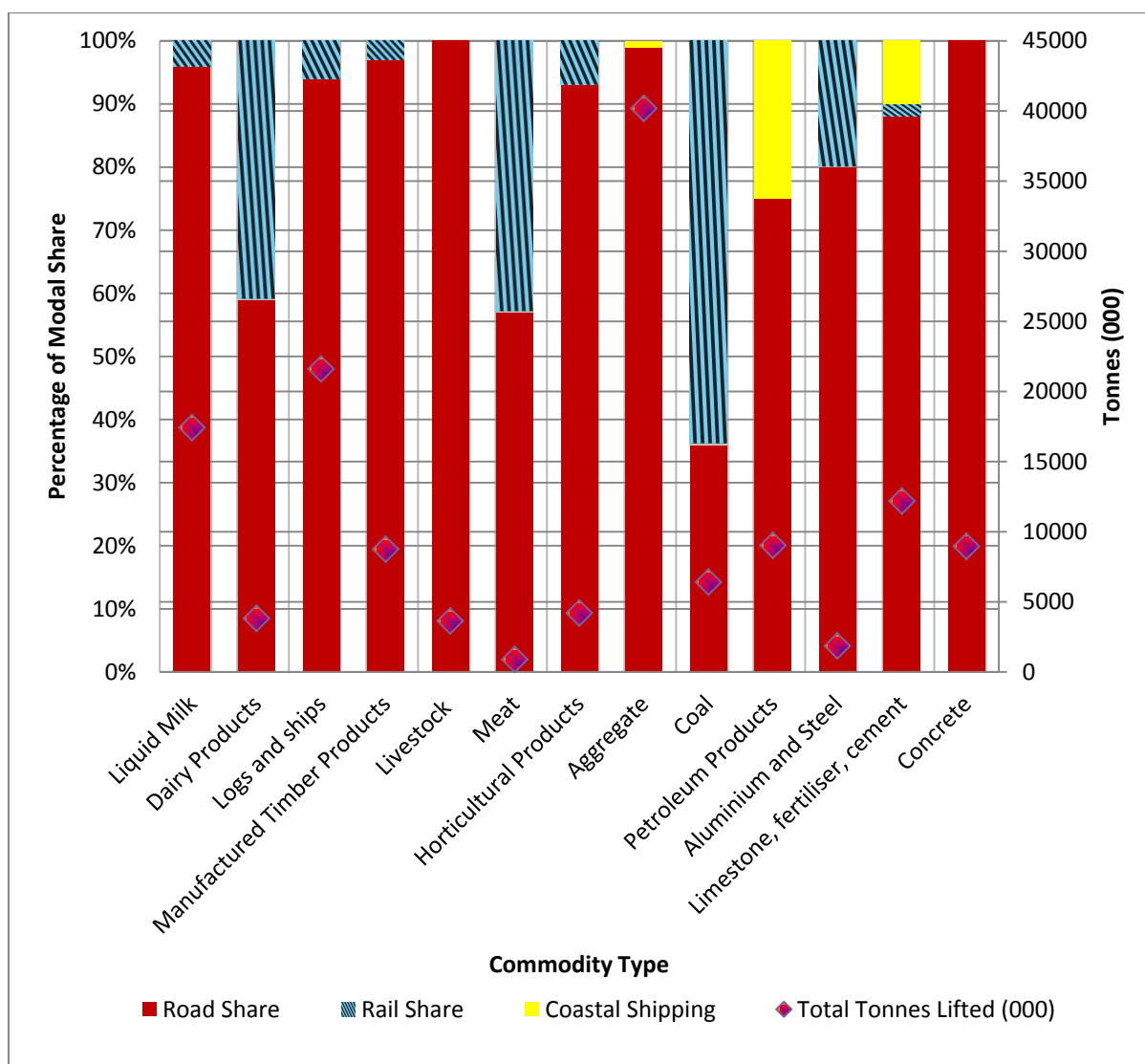


Figure 3.3.3 : Mode share for selected commodities (Paling, 2008)

### 3.4 Existing Freight Network Infrastructures in New Zealand

Here we present the current key infrastructure of the freight network in New Zealand. It comprises of the Road Network, Rail Network and Ports.

1. **Road Network** – The road infrastructure in New Zealand is summarised in Table 3.4.1.

**Table 3.4.1 : Categories of roads in New Zealand**

Categories	Total Length	Percentage of Total	Percentage of Vehicle-kms travelled
State Highways	11,000 km	12%	50%
Local Roads	83,000 km	88%	50%

Aside from the network itself, other road services such as drayage operations provide the essential intermodal components for rail, international and coastal shipping movements. Trucking is the mode choice for many shippers and manufacturers as it offers flexibility especially in the last-leg service, fast, reliable and higher handling quality.

**2. Rail Network** – The utilisation of New Zealand rail network is summarised in Table 3.4.2.

**Table 3.4.2 : New Zealand rail network utilisation**

Freight Route	Freight Services Per Day	Line Capacity Utilised	Gross Tonnage	% North Bound	% South Bound
Auckland-Wellington – Christchurch	8	77%	2,870,231	43%	57%
Auckland – Tauranga	13	80%	3,588,084	61%	39%
Christchurch – Dunedin – Invercargill	9	75%	1,840,299	56%	44%
				% East Bound	% West Bound
West Coast – Christchurch	11	51%	2,468,958	99%	1%
Hawkes Bay – Taranaki	13	60%	850,072	16%	84%
Other Lines			3,839,191		

New Zealand rail infrastructure has suffered from significant underinvestment problems. In 2008 only 4,000 km of rail tracks exist to service both freight and passenger operations down from 5,689 km in 1953 (Rockpoint, 2009). Rail operations are impacted by the age, design and condition of the country's rail infrastructure. New Zealand's rail system operates for the most part with an 18 tonne maximum axle load whereas world standards are 25 tonnes per axle load. Bridges, tunnel clearances and steep gradients in the network restrict the weight, height and speed of rail freight. While recent investment has targeted key areas of restriction, bridges remain a major network issue and until addressed, track upgrades elsewhere are unable to be fully utilised (Rockpoint, 2009).

**3. Coastal shipping** – New Zealand is currently serviced by 16 key ports and summarised in Table 3.4.3.

**Table 3.4.3 : New Zealand key ports (Rockpoint, 2008)**

Port	Location/City, Region	Container Terminal	Port Type
North Port	Marsden Point, Whangarei, Northland	No	Bulk
Ports of Auckland	Waitemata Harbour, Auckland	Yes	International
Ports of Auckland	Onehunga (Manukau Harbour), Auckland	No	Coastal
Ports of Tauranga	Sulphur Point, Mt Maunganui, Bay of Plenty	Yes	International
Eastland Port	Gisborne, Poverty Bay	No	Bulk
Port Taranaki	New Plymouth, Taranaki	Yes	Bulk
Port of Napier	Napier, Hawkes Bay	Yes	Regional
CentrePort	Wellington	Yes	Regional

Port Marlborough	Picton, Marlborough	No	Bulk
Port Nelson	Nelson, Tasman	Yes	Regional
Port of Westport	Westport, West Coast	No	Coastal
Port of Greymouth	Greymouth, West Coast	No	
Lyttelton Port	Lyttelton, Canterbury	Yes	International
PrimePort Timaru	Timaru, South Canterbury	Yes	Regional
Port Otago	Port Chalmers, Dunedin, Otago	Yes	International
SouthPort	Bluff, Invercargill, Southland	Yes	Bulk

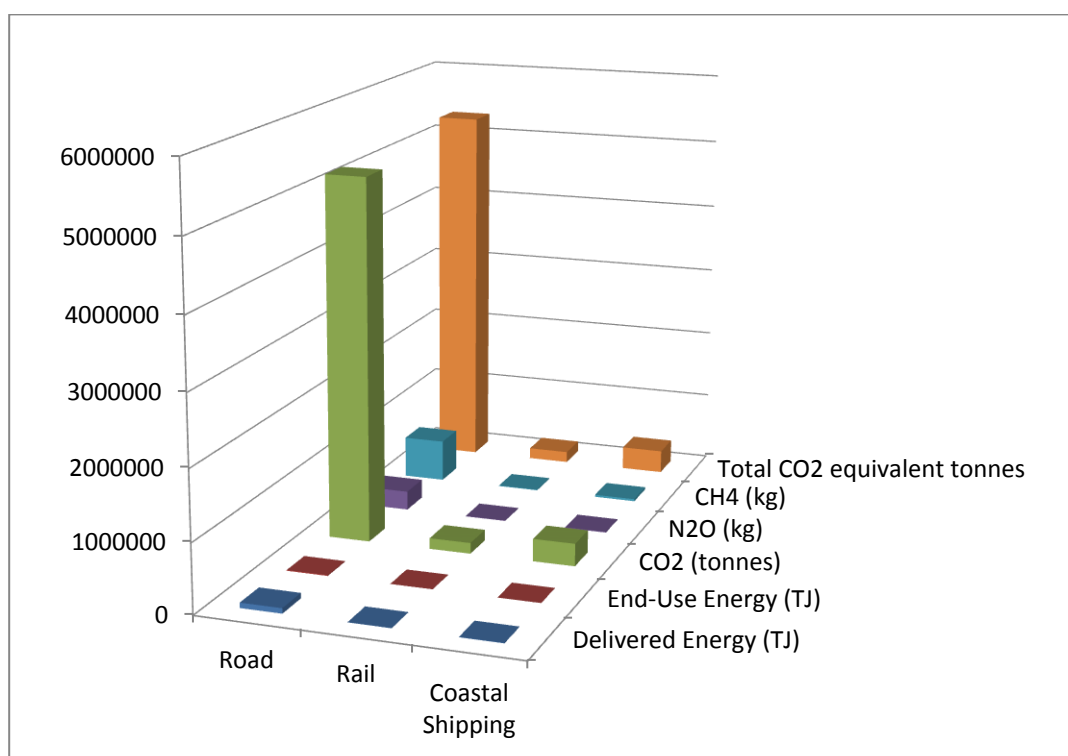
New Zealand has only 16 commercial freight ships, the rest of the commercial fleets are for tourism and fishing purposes (Rockpoint, 2009). Historically, the country is heavily reliant on maritime trade owing to its topography. All of the 270,000 square-km landmass is less than 100 km away from the coast. However with improved land transport infrastructure, coastal shipping became less attractive as a means of transport.

These three modes of freight transport in New Zealand cater to different markets. At present, road is the best option for time-sensitive and short-haul freight. Meanwhile, rail serves in-bulk, heavy and/or long-distance freight wherein a high proportion is to and from industrial plants, mines and ports. Lastly, coastal shipping is also used for bulky, heavy, long-distance, non-time-sensitive freight. It is not cost-effective for short-distance freight because of the transfer costs and the lack of accessible inland routes which is especially true for intra-island distribution (New Zealand Productivity Commission, 2012).

### 3.5 New Zealand Data for Energy and Emissions

Road transport is the single biggest energy user in New Zealand and with less than 1% using renewable fuels, this sector offers considerable potential for energy savings and emissions reductions (EECA, 2010-2011). In total, the freight sector accounts for approximately 43% of the total energy consumed by the transportation sector (Paling, 2008).

The following data summarises the freight transport sector comprising of the three main modes of road, rail and coastal shipping and their total energy and emissions per annum (EECA, 2010-2011).



**Figure 3.5.1 : Energy and emissions comparison of road, rail and coastal shipping**



The data presented on the website are not exact values but are extracted from models and estimations. They are obtained from organisations such as the Ministry of Economic Development (MED), Ministry of Transport (MOT) and Statistics New Zealand. Surveying is the general method used to collect information from different sectors. The country's biggest industries were surveyed for their fuel consumption and fuel intensity rates and from these values, the end-use energy and greenhouse gas emissions were calculated using thermodynamics assumptions such as the higher-heating value, fuel content or efficiency, heat lost, amongst others.

Regional breakdown of the results were derived from estimates of the industrial activities for each region and by augmenting the computed figures with spatial data in the regional, territorial authorities and mesh block levels such as employment counts, resident population, household space heating, agriculture sector data, temperature data and railway coverage (Patterson and McDonald, 2009).

### **3.6 Modal Shift Potential in New Zealand**

In New Zealand, forecasts shows that road will remain the dominant mode for freight transport in the foreseeable future and only up to 7% of road freight may be shifted to rail (NZBC, 2011). However, the government has a clear vision of an affordable, integrated, safe and sustainable transport system paving way to two legislative frameworks for New Zealand Transport Strategy. The National Rail Strategy to 2015 (MOT, 2005) and domestic sea freight strategy (MOT, 2008a) have the following target goals by 2040 in order to achieve national energy efficiency and environmental goals:

- a) Increase rail share of freight to 25% of tonne-kilometres.
- b) Increase coastal shipping's share of inter-regional freight to 30% of tonne-kilometres.

The multinational dairy company Fonterra has recently published a report about 20% savings in fuel and CO<sub>2</sub> by increasing rail share in their freight operations (EECA, 2011b). See Table 3.6.1 for the actual values. However, it is worth noting that this strategy of Fonterra is in line with centralisation of operations in the Waikato region as a way to take advantage of the regions geographic competitive advantage. Fonterra's study lies on the economic benefits of mode shift and is distinct from the main objective of our research which aims to investigate modal shift from an impartial perspective.

**Table 3.6.1 : Daily traffic in north island (million net tonne-kms) (EECA, 2011)**

Year Mode	2005			2010		
	Road	Rail	Total	Road	Rail	Total
Waikato	46.9	51.3	98.2	21.8	66.4	88.2
Northland	10.3	41.3	51.5	18.8	23.7	42.5
Total	57.2	92.6	149.8	40.6	90.1	130.7

## **Chapter 4: Theoretical Framework and Research Methodology**

This chapter explains the conceptual framework and methodology used in the study.

### **4.1 Model Overview**

In order to understand the dynamics of freight transportation and production in the context of energy and emissions constraints, a model called the “*Geographic Adaptive Potential*” or GAP was developed. It is a quantitative measure of the ability of the freight and production system to reduce fuel consumption and emissions while delivering the same amount of goods. In other words, GAP measures the capacity of the system to adapt given the constraints. It is a geography-based assessment of the system which is independent of behavioural and economic dimensions from both the supplier and consumer perspective.

It is well-known from the review of literature that the decisions and strategies across all levels in the supply chain are heavily-influenced by suppliers and consumers’ behaviour, perception, preference and willingness to change as well as socio-political situations. As a result, dealing with the complex realm of supply chain economics hinges on trend forecasts or predictions which are subject to partiality of the modelling assumptions.

For this reason, this research used a purely geographic approach in analysing freight transportation and production. The goal is to present an innovative method that looks at this system in a highly objective fashion and not relying on predictions. Parameters requiring econometric measures such as monetary costs will be derived from geospatial

properties of the model network such as distance and mode choice. Geographical data is utilised as proxies for economic measures required in the models. The resulting geographic-based model examines and evaluates the capacity to alter in the systems' dynamics instead of giving forecasts of what changes will occur or measure the probabilities that these changes will occur. The GAP approach is described in Figure 4.1.1.

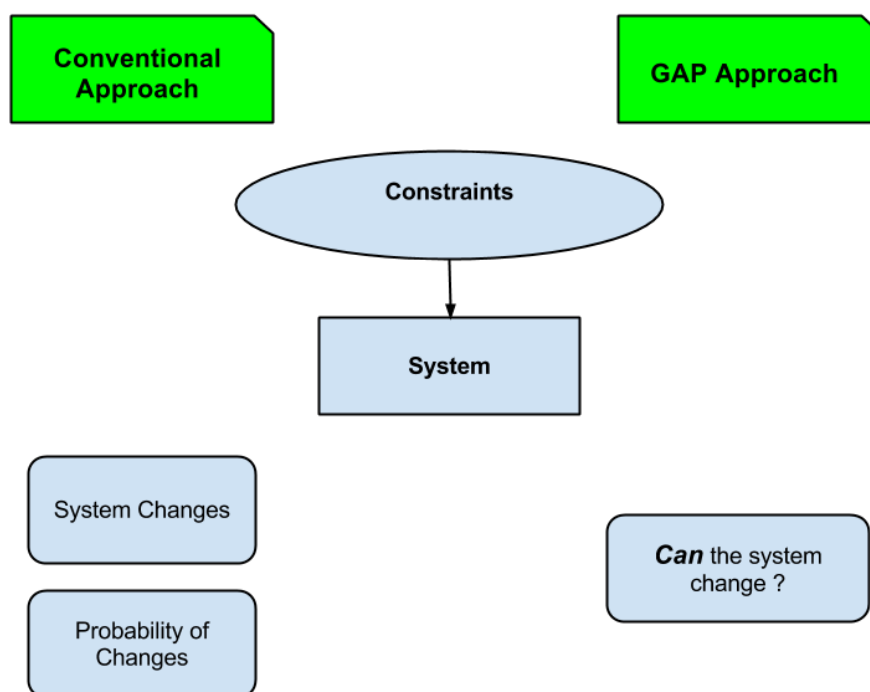
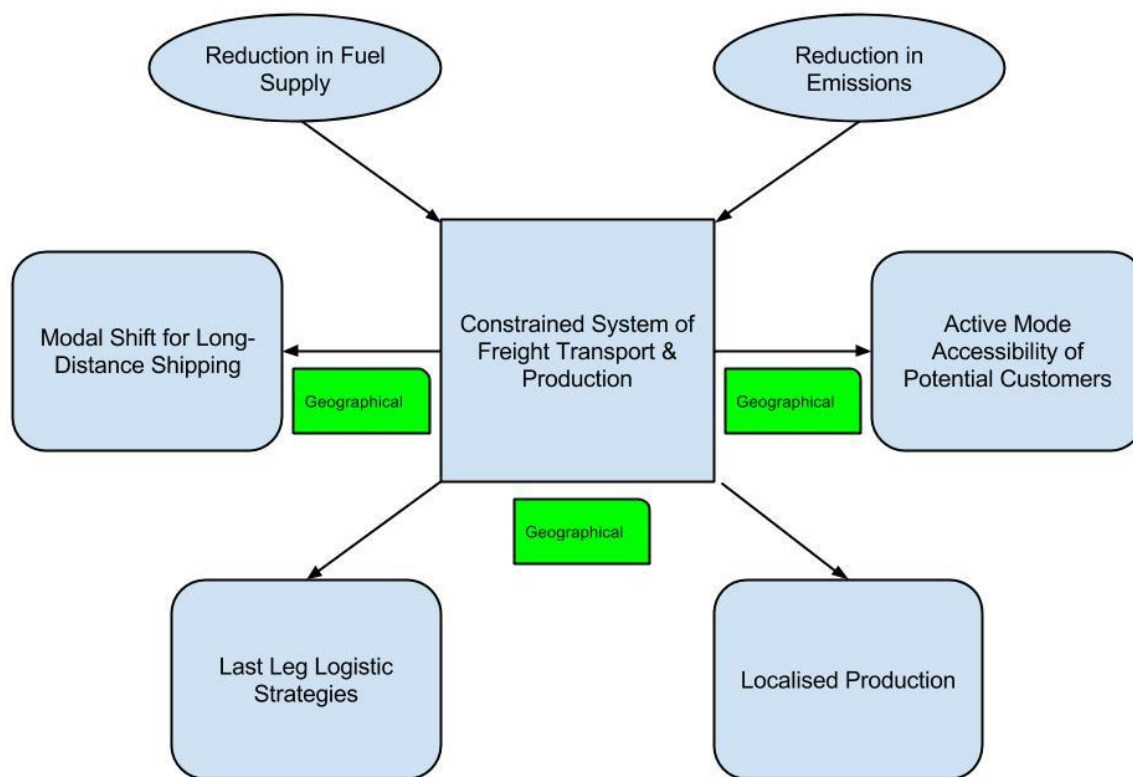


Figure 4.1.1 : The GAP approach

## 4.2 Theoretical Framework



**Figure 4.2.1 : Theoretical modelling framework of GAP**

The hypothesis of the model is that constraints in fuel supply and greenhouse gas emissions will bring about changes in the dynamics of freight transport and production. Instead of deriving a constrained model where we predict shift in the economic paradigm and its interplay with the logistical decisions of the private sectors and role of the consumers as stakeholders, the freight transport and production systems' capacity to change was presented in terms of 4 components based on its geospatial aspects. These four components are illustrated in the Figure 4.2.1.

### 4.3 Formulation of the Geographic Adaptive Potential Models

Consider the following simplified diagram where products or commodities are sent from origin  $O$  to destination  $D$ . In Figure 4.3.1, this commodity flow is depicted by using  $t1$  trucks, the second  $t2$  trucks and the last link using  $t3$  trucks to ship from  $O$  to  $D$ .

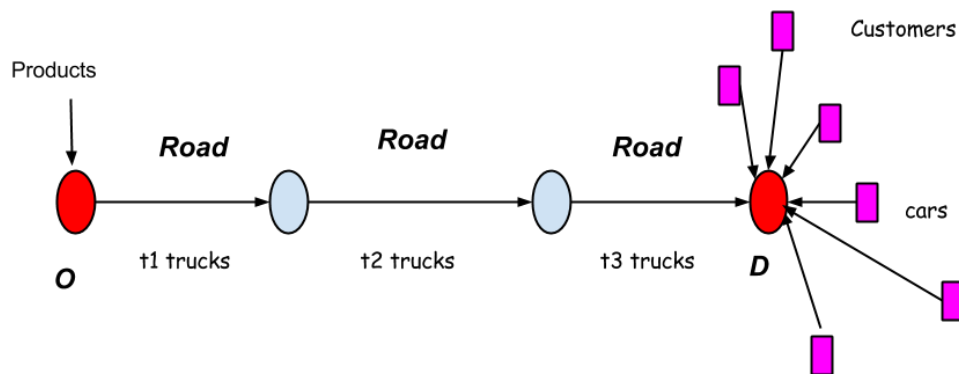


Figure 4.3.1 : Hypothetical commodity flow on the supply chain

We used the term ‘scenario’ for consequences of postulated events or occurrences, which in this case are the inherent system risks associated with peak oil and climate change. Scenarios must be distinguished from future predictions or forecasts based on the postulated events. The scenarios targeted to the specific links in the supply chain as illustrated in Figure 4.3.1. Define  $ND(A,B)$  as the total distance of traversing the network of links from point  $A$  to point  $B$ .

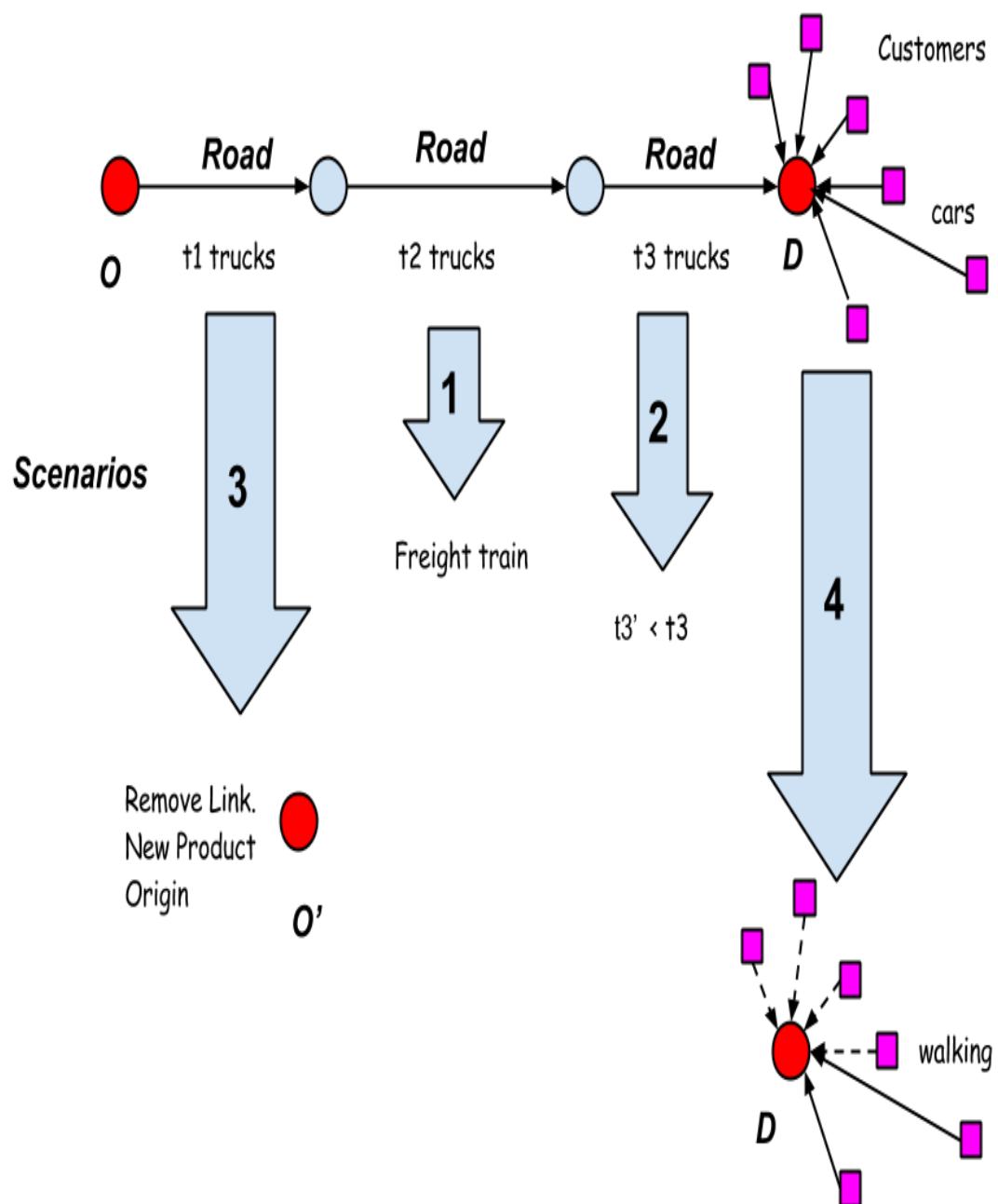


Figure 4.3.2 : Links on the supply chain and GAP formulation

**Scenario 1:**

Given that the appropriate intermodal infrastructures are available and in place, modal shift of this origin-destination freight flow alters the middle link in the chain. This means that  $t1$  and  $t3$  trucks are still used for the first link and third link, respectively while 1 freight train replaces the  $t2$  trucks.

**Scenario 2:**

Now, consider the scenario where the last leg of the chain is altered. As discussed in Chapter 2.5, the last leg usually occurs in the urban environment, wherein freight trips are equivalent to truck trips which significantly impact urban congestion. By improved freight logistic strategies such as better consolidation, vehicle routing of trip chains, the number of truck trips may potentially be reduced while distributing the same amount of goods. Here, the issue of product essentiality is raised with non-essential goods being removed in the commodity chain to reduce the freight trips. Here, where  $t1$  trucks are used for the first link,  $t2$  trucks for the second link while  $t3'$  trucks for the third link where  $t3' < t3$  for the third link.

**Scenario 3**

The next scenario is reducing the number of links in the chain. Assume that destination  $D$  is an urban environment or residential vicinities and hence are considered fixed in their specific location. This scenario investigates the potential ability of local production system to supply for the said destination  $D$ . That is, let the commodities come from a new destination  $O'$  instead where  $ND(O',D) < ND(O,D)$ .



## Scenario 4

The last scenario deals with the consumers' access to the destination  $D$  which is now considered as a marketplace. Consider customers  $c1, c2, c3, \dots, cn$ . We determine the  $ci$ 's for which  $ND(D, ci) < W$ , where  $W$  denotes the threshold for the walking access to the network.

## 4.4 Model Summary

The four scenarios presented in the previous section forms the foundation and components of the 'Geographic Adaptive Potential' (GAP) model. As in the previous discussion, these four components represent different links of the transport supply chain where the analysis and prescribed mitigation strategy is applied. The scenarios are not independent of each other and may co-exist simultaneously. The following outlines the details of each component of the model.

Firstly, to evaluate the potential of modal shift, we need a visualization tool to analyse intermodal freight networks. Here, we created the 'New Zealand Intermodal Freight Network' (NZIFN) model using ArcGIS. This model uses deterrence parameters such as operational costs and time-of-delivery as well as energy consumption and emissions, evaluates trade-offs, and finds the most optimal route from a given origin to a destination. The NZIFN is applied to hypothetical scenarios of distribution from Auckland to Wellington and Auckland to Christchurch which demonstrates how freight mode choices impact different costs associated with freight movement and the potential savings of moving by rail or shipping. The NZIFN model was presented in Chapter 5.

The second component of the model deals with last leg logistics strategies. Here, we examined truck trip rates in the urban setting and how much effect they have on businesses in that environment. In particular, we focussed on the truck trip generation rates of different food distribution systems namely supermarkets, convenience stores, bulk food store and the Farmer's market. Data gathering for this study is done via survey, manual truck counts and driver interviews. Analytic methods were performed on the store characteristics used as input parameters to determine their influence on the truck trip generation of the stores. Chapter 6 discussed the Last leg logistic strategies.

The third aspect of the research is the localisation of production. This subject explored the potential of the Farmer's market model of production and distribution and compared it with the conventional supermarket system. Data used will be from interview with farmer's market and integrated with the GIS database. The topic of localised of production is covered in Chapter 7.

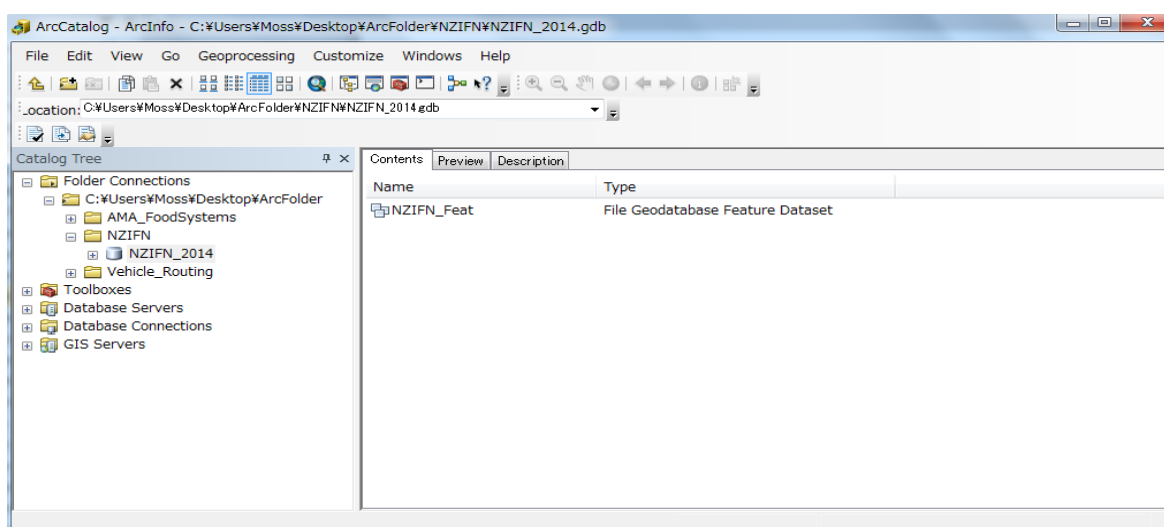
The fourth part will tie up the three results for freight with customer accessibility. We would like to determine how many customers can access the supermarkets and Farmers' markets by walking. This uses the GIS Active Mode Analysis (AMA) tools developed in (Rendall et al., 2011). Customer accessibility is covered in Chapter 8.

## **4.5 Modelling in ArcGIS**

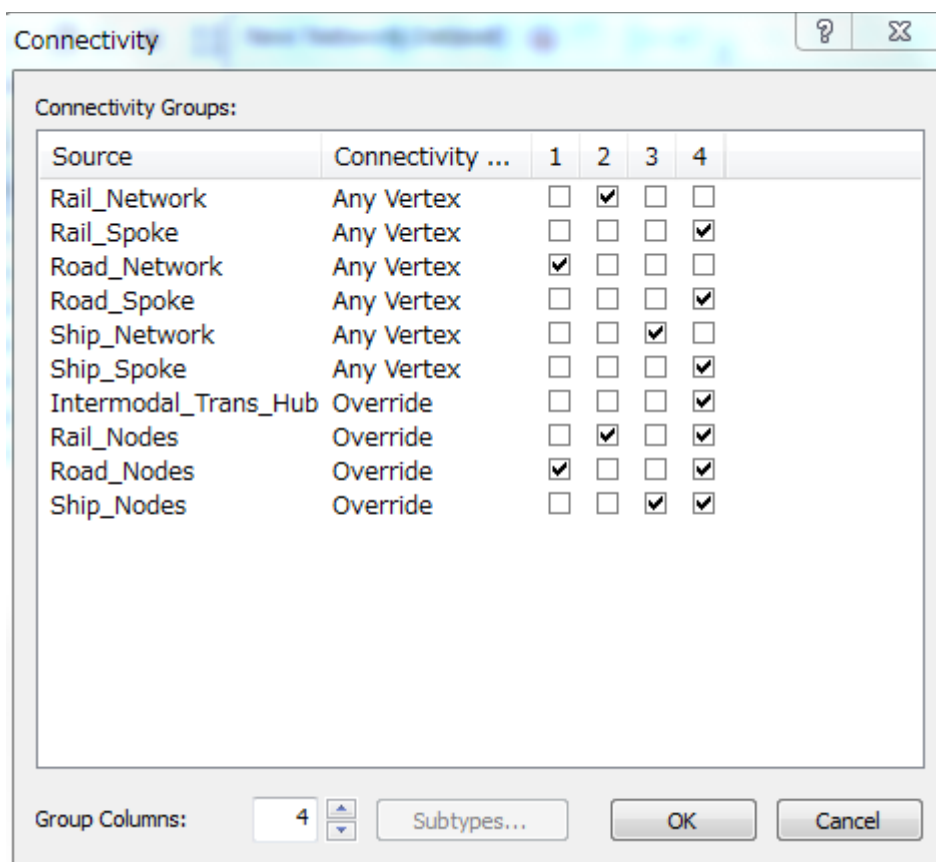
ArcGIS is a complete system of applications used for creating, collecting, organizing, managing, analysing and distributing geographic information. It is produced by Environmental Systems Research Institute or ESRI (ESRI, 2013). The models presented in

this dissertation were implemented through a network-based spatial analysis in the ArcGIS for Desktop platform. In this section, a brief overview of generic models for network analysis is presented.

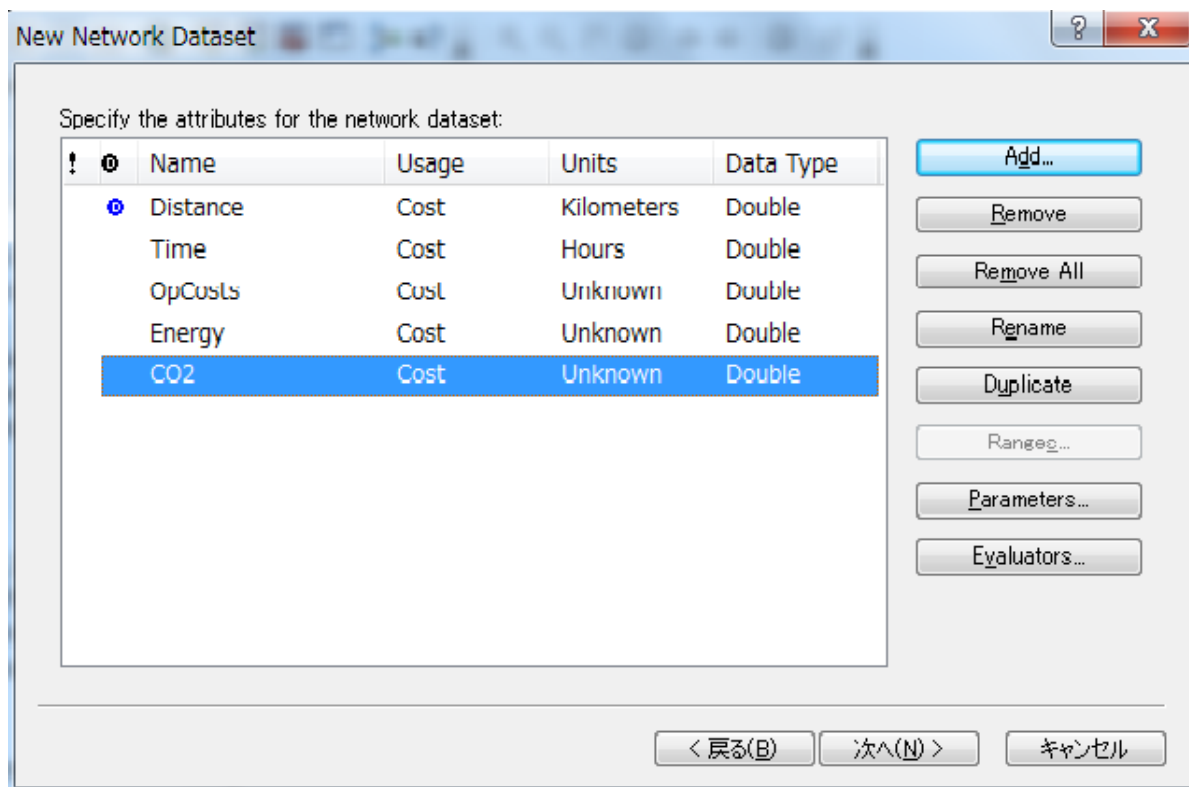
ArcGIS has an application called ArcCatalog which is used to view, organise and manage geodatabases for ArcGIS Desktop. See Figure 4.5.1 for a screenshot of the ArcCatalog application. Using ArcCatalog, network data sets are created in a 'File Geodatabase Feature Data Set' which contains the junctions (or nodes), edges and turn elements. Edges are the links that connect the junctions with each other. At the same time, junctions connect the edges and enable directional flow within the network. Turn elements provide the information about movement between the edges. There are two main steps in creating a network data set. First is to determine the connectivity policy between the network elements and in particular using 'connectivity groups' to model multimodal (or intermodal) transportation systems. The next task is to specify travel impedances for the network such as cost parameters like distance, time, and monetary cost, amongst others. These steps are illustrated in the screenshots in Figures 4.5.2 and 4.5.3.



**Figure 4.5.1: ArcCatalog geodatabase view**



**Figure 4.5.2: Network data set connectivity policy**



**Figure 4.5.3: Network dataset impedance parameters**

Once the network data set is built, it can be displayed using the ArcMap application. The 'Network Analyst' extension must be activated in order to perform the necessary analysis method. See Figure 4.5.4 for a screen shot of the network analyst tool in ArcMap. On a given network data set, the fundamental tool in network analysis is solving for the "best" possible route from a given origin to a destination or for a sequence of three or more locations. Depending on the user-specified impedance, this "best route" may be the shortest-distance route, the quickest route or whatever is specified by the user (ESRI, 2012). See Figure 4.5.5 for a screen shot of the settings of the Network Analyst settings and attributes choice for impedance factor. Finally, ArcGIS has a built-in solver utilising Dijkstra's algorithm to obtain the solution for this route-finding optimisation problem. The best route analysis is used in Chapter 5.

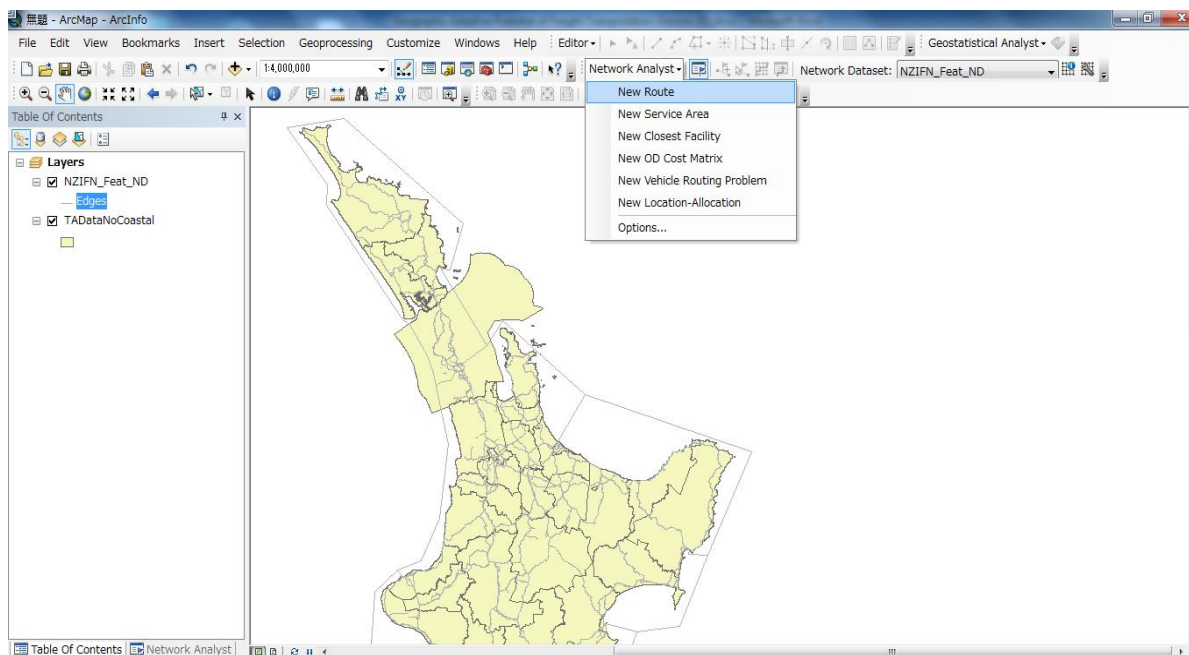


Figure 4.5.4: ArcMap Network Analyst tool

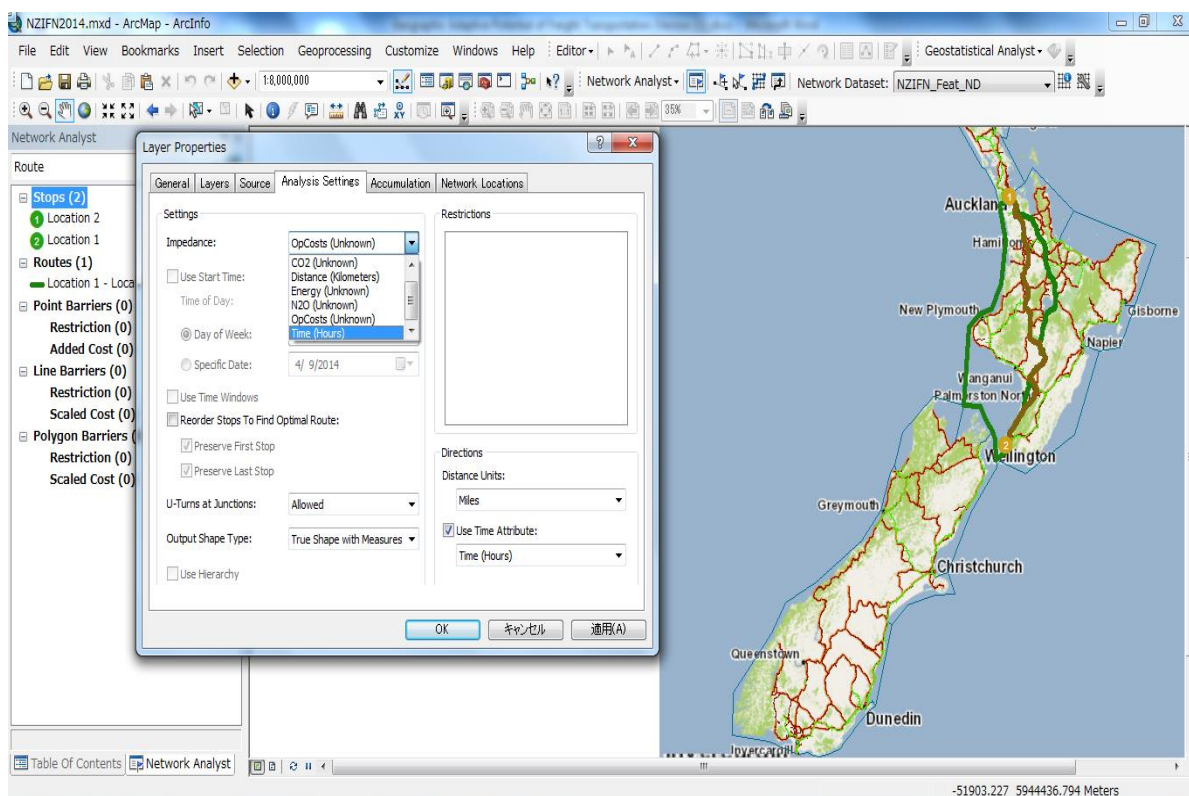


Figure 4.5.5: Network analyst settings and choice for impedance

Dijkstra's algorithm is used to find the shortest-path from origin  $o$  to destination  $d$ . In ArcGIS, the algorithm keeps a tally of the set of junctions  $J$  whose final shortest path from  $o$  has already been computed. It then iteratively finds a junction in the set of junctions that has the minimum shortest-path estimate, and adds it to the set of junctions  $J$ . Next it updates the shortest-path estimates of all neighbours of this junction that are not in  $J$ . The algorithm stops when the destination junction  $D$  is added to  $J$  (ESRI, 2012).

One extension of the route finding algorithm is to generate the optimal sequence of visiting a set of locations which is called the "Travelling Salesman Problem" or TSP and in particular its superset which is the "Vehicle Routing Problem" or VRP. In VRP, a set of orders or pick-up points need to be assigned to a set of vehicles such that the overall path cost from a depot is minimised. In ArcGIS, heuristics are used to solve this problem which starts by generating an origin-destination matrix of shortest-path costs between all order and depot locations along the network. An initial solution is determined by inserting the orders one at a time onto the most appropriate vehicle. This initial solution is improved by changing the sequence the orders on each vehicle, switch orders from one vehicle to another or exchange orders between the vehicles. The VRP solver is used in Chapter 7.

Another built-in solver used in this dissertation is the 'Service Area Analysis' which is also based on Dijkstra's algorithm. It returns a set of connected edges that are within a cut-off network distance from or to a specified location  $o$ . The solver generates polygons surrounding these edges. More details of this analysis is given on Chapter 8.

## **Chapter 5: Intermodal Freight Network and the Potential for Modal Shift**

As a prerequisite for evaluation of mode shift potential for freight, we first need a functioning and capable intermodal network to sustain such shift. This chapter presents a GIS-based optimisation model integrating road, rail and shipping network for New Zealand and is termed as the New Zealand Intermodal Freight Network (NZIFN) (Asuncion et al., 2012b).

### **5.1 Overview**

The intermodal freight transportation systems provide both competitive and cooperative freight transportation services with each mode offering advantages and disadvantages. For this reason, the model we created reflects these factors and used deterrence parameters such as operational costs and time-of-delivery as well as energy consumption and emissions, and evaluates trade-offs to find the most optimal route from a given origin to a destination.

The model is applied to hypothetical scenarios of distribution from Auckland to Wellington and Auckland to Christchurch of selected non-perishable commodities which demonstrates how freight mode choices impact different costs associated with freight movement and the potential savings of moving by rail or shipping.



## 5.2 Methodology

The modelling framework for the NZIFN uses a similar hub-and-spoke approach of Geographic Intermodal Freight Transport or GIFT network of North America (See Figure 2.5.1 in Chapter 2.5). The GIFT modelling technique is utilised for the available New Zealand data. These are combined with the information we have collected in our surveys of ports and rail sector (See Appendix C.1 and C.2). Several pre-processing and data sanitisation steps were required before they can be readily implemented in the ArcGIS platform. Several Python scripts for geoprocessing were written to perform the pre-processing step.

Even if the bulk portion of the model entails programming for GIS applications, some of the parameters necessary for the model such as rail yards and shipping ports data were not available in literature of freight in New Zealand, hence surveys are conducted to obtain the gaps in the current information.

For clarity, we divide the steps into 3 major categories namely, a) Creation of geospatial intermodal freight network, b) Assigning costs or impedance variables on each network, c) Determining freight flows and scenario analysis. A step-by-step outline, together with the data availability and appropriate data collection methods were given on Figure 5.2.1. Each of these steps will be discussed in detail in the succeeding subsections.

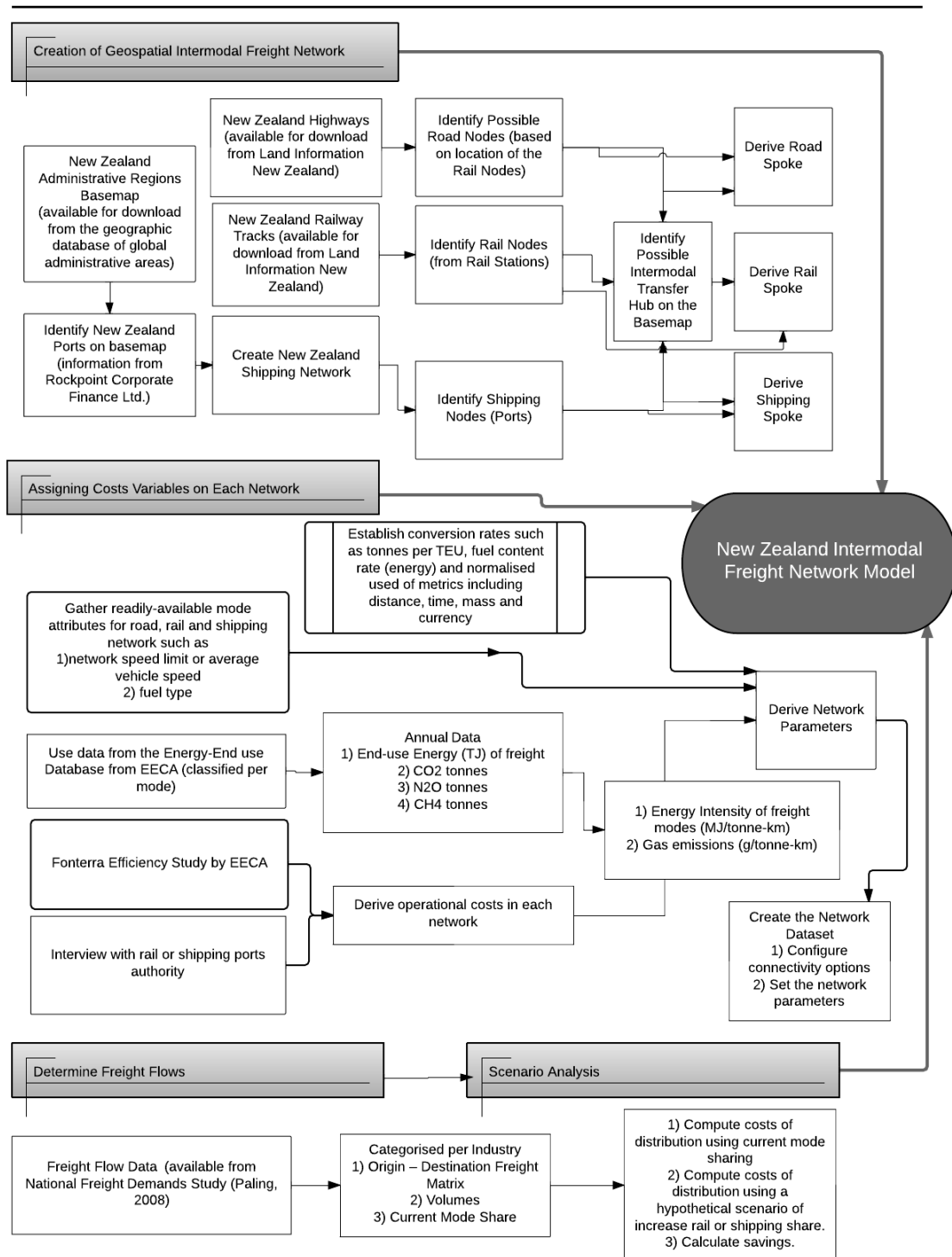


Figure 5.2.1 : Summary of the modelling steps for NZIFN

## 5.3 The NZIFN Model and Case Studies

### 5.3.1 Creation of geospatial intermodal freight network for New Zealand

There are several existing geospatial datasets in New Zealand which were used in the creation of NZIFN and are readily available for download online. These are the 'Improved New Zealand Road Centrelines', 'New Zealand Railway Tracks' and 'New Zealand Railway Stations', all created by Land Information New Zealand (LINZ) (Land Information New Zealand, 2011b).

The road network was constructed from the State Highways category of New Zealand Road Centrelines including connectivity segments such as roundabouts and on-off ramps. As a pre-processing step, this road network was tested for its self-connectivity using ArcGIS 10 Network Analyst to ensure that routings from any random origin and destination are allowed.

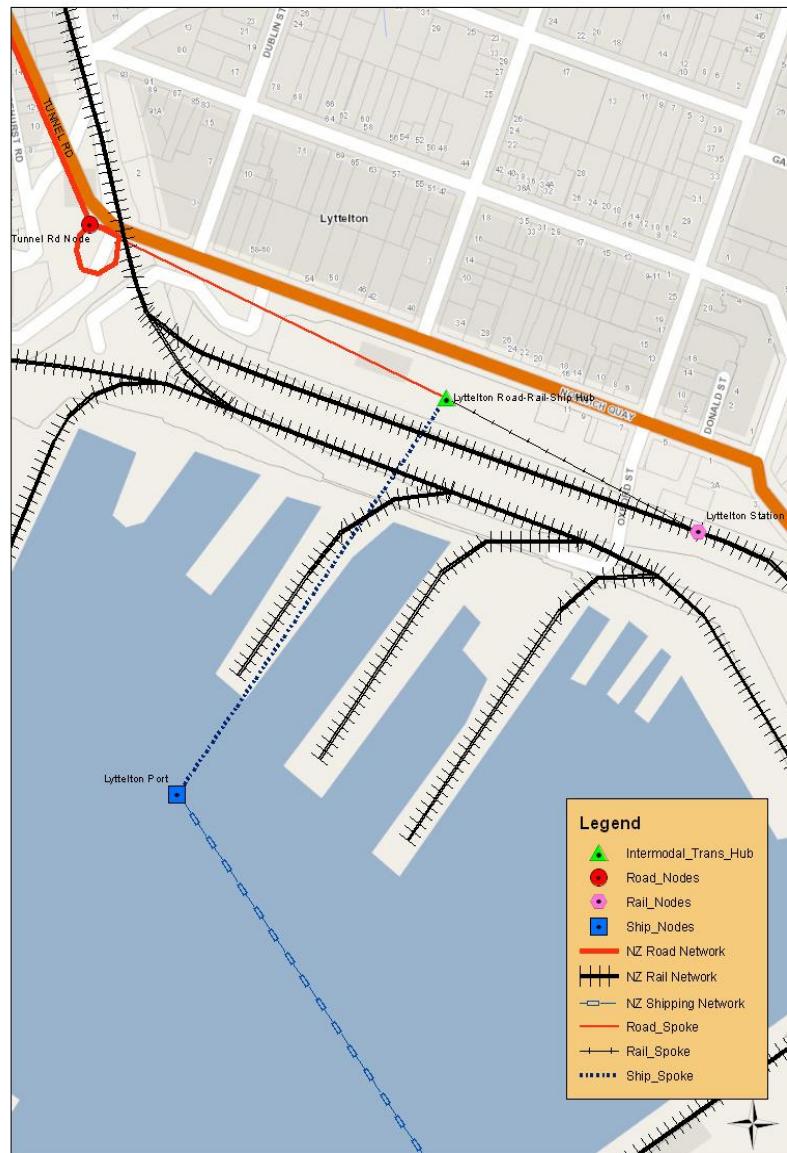
The rail network was built from the Zealand Railway Tracks. The shipping nodes were created using the 16 port locations given in Chapter 3.C. The rail nodes were derived from a subset of the New Zealand railway stations and were chosen according to the descriptions in Table 5.2.1.

The New Zealand shipping network was made from the port geographical location given on the Chapter 3.4 ensuring connectivity between each port but does not use the actual shipping routes. The construction of the hub-and-spokes intermodal transport facility is illustrated in Figure 5.3.1 where each intermodal transport hub needs to be connected to road, rail and shipping spokes. The resulting intermodal freight network consists of 10 geospatial datasets and is summarised in Table 5.3.1.

**Table 5.3.1 : Summary of 10 geospatial datasets used for the NZIFN**

Description	Geomtery Type	Source and Processing Required	Content
Road Network	Polyline	Improved New Zealand Road Centrelines by LINZ (Land Information New Zealand, 2011b)  Pre-processed by the author	State highways including roundabouts, on-off ramps, and ensuring overall connectivity
Rail Network	Polyline	New Zealand Railway Stations by LINZ (Land Information New Zealand, 2011a)	Entire railway tracks shapefile
Shipping Network	Polyline	Created by author	Artificial network created using 16 key ports of the country
Intermodal Transfer Hub	Points	Created by author	Artificial points/nodes selected near port locations and/or railways stations which can serve as a transfer facility
Road Nodes	Points	Created by author	Artificial points/nodes on the road network selected near the created Intermodal Transfer Hubs
Rail Nodes	Points	New Zealand Railway Stations by LINZ (Land Information New Zealand, 2011a)	A subset of the railway stations which are near the created Intermodal Transfer Hubs

		Pre-processed by the author	
Shipping Nodes	Points	Created by author	16 New Zealand key ports described in the previous section
Road Spokes	Polyline	Created by author	Artificial connection from road nodes to intermodal transfer hub
Rail Spokes	Polyline	Created by author	Artificial connection from rail nodes to intermodal transfer hub
Shipping Spokes	Polyline	Created by author	Artificial connection from shipping nodes to intermodal transfer hub



**Figure 5.3.1 : Construction of the intermodal network**

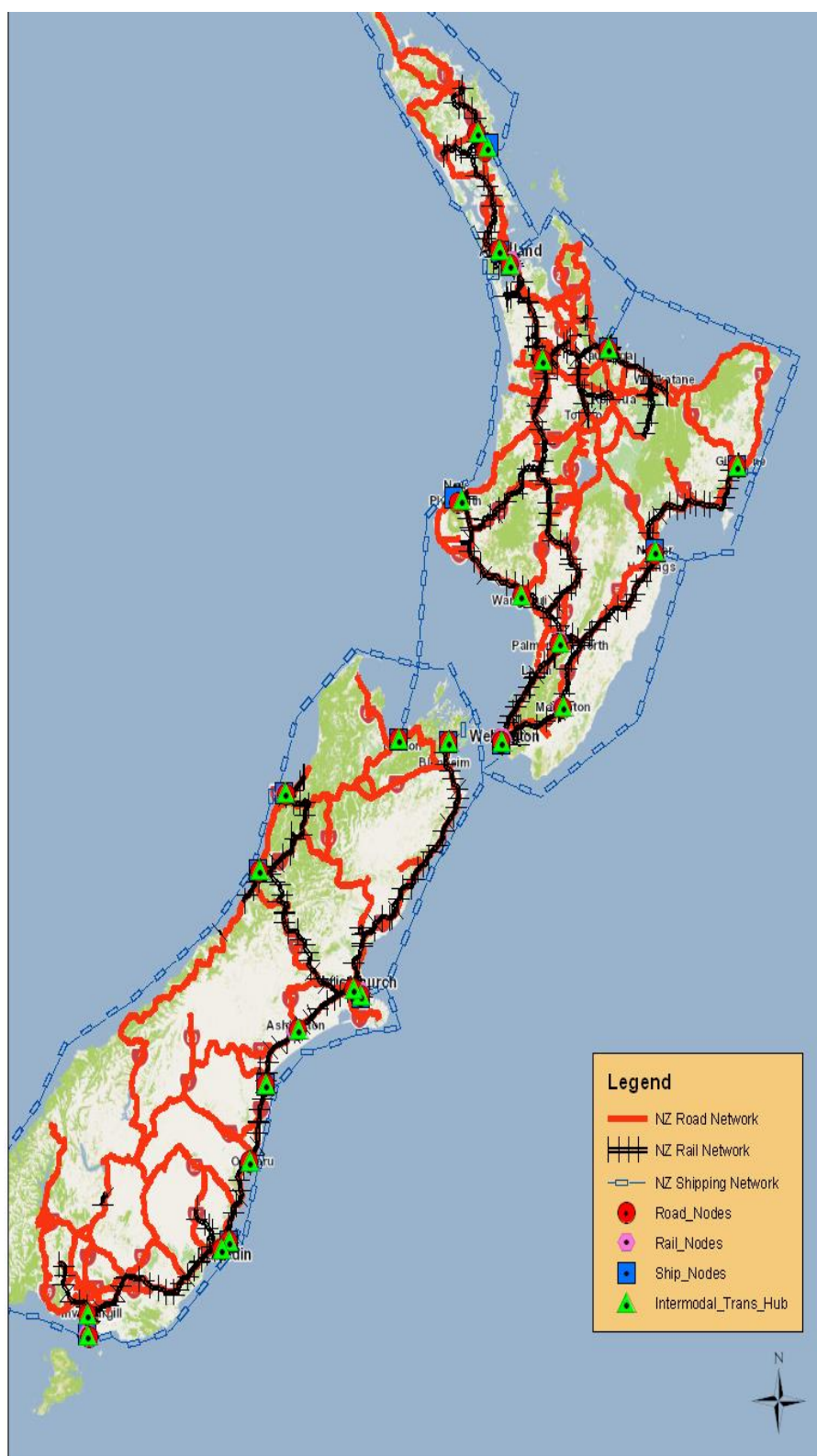


Figure 5.3.2 : The New Zealand Intermodal Freight Network (NZIFN)

### **5.3.2 Assigning Cost Variables on Each Network**

Network attributes or deterrence functions were assigned to each of network and spoke dataset. Deterrence in the network are also viewed as costs or impedance assigned in the system. Hence, from here on these terms may be used interchangeably.

In this model, the point datasets do not have any costs associated on them, but instead transfer penalties were assigned to the usage of the corresponding spokes. The first deterrence function is the geographical distance or shape length of each segment of the network and spokes which can easily be calculated in ArcGIS 10. The next attribute is time and this is obtained by dividing the distance with the speed allowed on the network (eg. Speed limits for New Zealand roads were provided in the original dataset).

The operation cost parameter was derived from surveys with rail management and ports in New Zealand (See Appendix D.1, D.2 for a copy of the questionnaire and privacy information sheet distributed to the corresponding organisation). Labour costs and fuel costs are the two main components of the total freight operating costs. Some costs estimates were also derived from the joint research effort of the Energy Efficiency and Conservation Authority or EECA and the Waikato Regional Council (EECA, 2011b) as well as the diesel price in New Zealand during the time of the study which is July 2012 (Stockdale, 2012). Unfortunately, due to commercial sensitivity of this type of information, the values were presented in an aggregated format and actual costs breakdown were obscured.

Other attributes such as the end-use energy and greenhouse gas emissions such as carbon dioxide [CO<sub>2</sub>], nitrous oxide [N<sub>2</sub>O] and methane [CH<sub>4</sub>] parameters were calculated using the transport sector values from the 'Energy end use database' of EECA (EECA, 2011a).



In Table 5.3.2, the conversion parameters used in the computations are presented. These values were mostly based on our interviews with the rail and shipping companies in New Zealand as well as their respective annual performance review.

**Table 5.3.2 : Conversion of units/parameters for the study**

1 Terra joule = $10^6$ Mega joule
1 kg = $10^3$ grams
1 TEU = 13 tonnes for road freight
1 TEU = 16.46 tonnes for rail freight
1 TEU = 34.4 tonnes for shipping
Fuel cost = 1.51 NZD for 1 litre of fuel
Fuel cost to Labour cost ration = 30%-70%

**Table 5.3.3 : Data for different freight modes in New Zealand**

Mode of Transport	Speed (kph)	Operational Costs (\$/TEU-km)	Energy (MJ/TEU-km)	CO <sub>2</sub> (g/TEU-km)	N <sub>2</sub> O (g/TEU-km)	CH <sub>4</sub> (g/TEU-km)
Road	By road class*	3.31	12.27	5370.88	0.28	0.63
Rail	45	1.70	6.46	963.41	0.04	0.06
Ship	25	1.63	8.69	4198.49	0.12	0.41

\*Road class speed ranged from 20-110kph

**Table 5.3.4 : Data for intermodal transfer penalties**

Transfer Facility	Time (hr/TEU)	Operational Costs (\$/TEU)	Energy (MJ/TEU)	CO <sub>2</sub> (g/TEU)	N <sub>2</sub> O (g/TEU)	CH <sub>4</sub> (g/TEU)
Road/Rail/Shipping Spoke	1	109.14	20.10	8794.47	0.46	1.02

### 5.3.3 Model Validation

The model validation step for NZIFN was not conducted at this stage of the research. As mention, the NZIFN is a direct adaptation of the North American GIFT model applied to New Zealand setting. The GIFT model was validated and tested for the intermodal freight network of the Delaware region (Corbett and Mokashi, 2011). The research is aimed at aiding in the decision-making process related to the utilisation of highways and waterways in the region.

One main difference of NZIFN with GIFT was their chosen network impedance attributes. Both models incorporate the time, operational costs, energy and carbon dioxide [CO<sub>2</sub>] parameters however while GIFT measures pollutants such as particulate matter [PM<sub>10</sub>] and sulfur oxide [SO<sub>x</sub>], the NZIFN model evaluates the values for nitrous oxide [N<sub>2</sub>O] and methane [CH<sub>4</sub>] emissions. The reason for this difference is due to the available data for freight transport and emissions in New Zealand.

## 5.4 Case Analysis

Using Network Analyst toolset in ArcGIS 10, the NZIFN model was tested on three case studies to investigate intermodal route optimisations based on time, operating costs, energy, and environmental objectives. The first case analysis is the distribution from

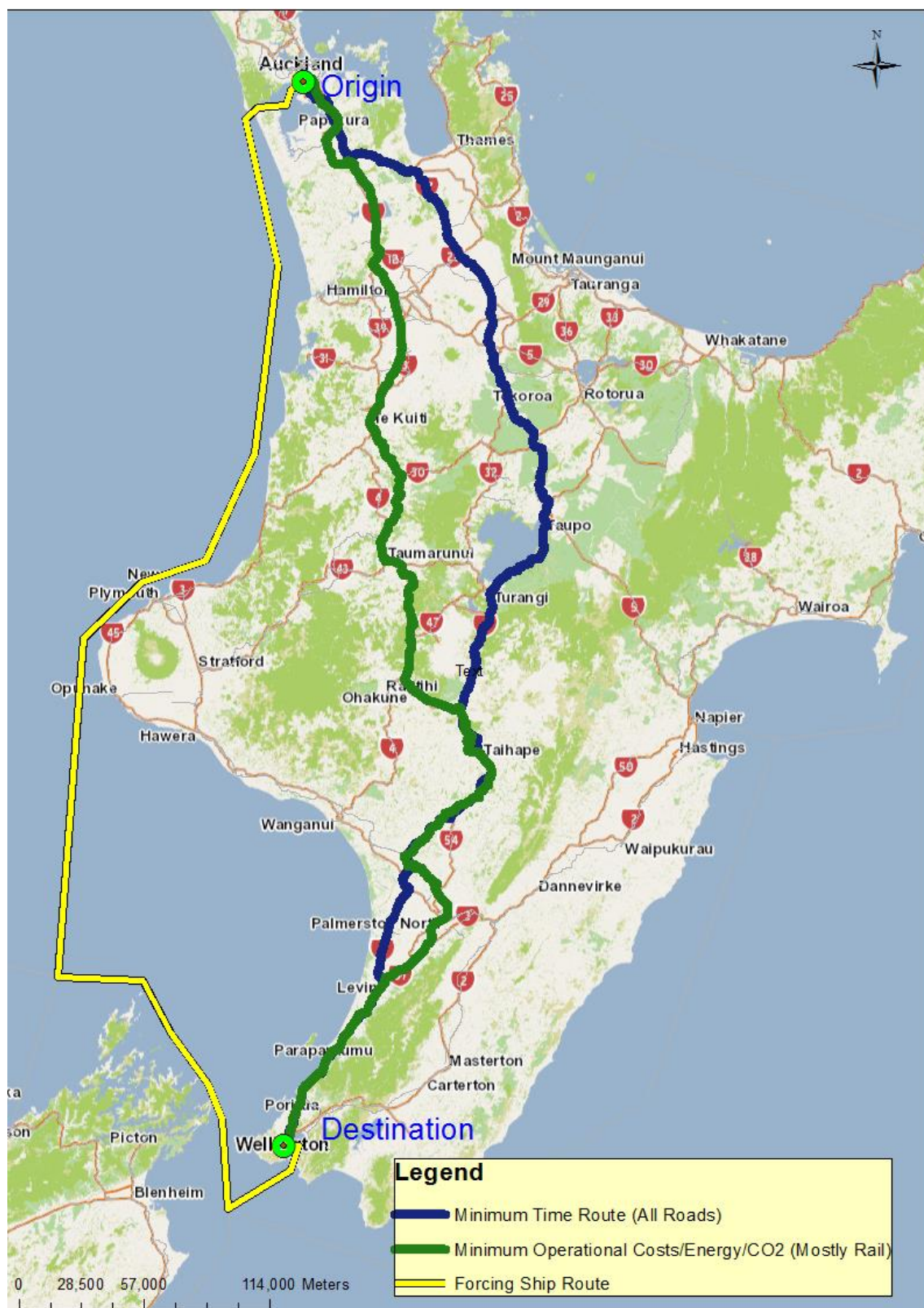
Auckland to Wellington, the second is from Auckland to Christchurch and the last is from West Coast to Christchurch. The minimum time, operating costs, energy, and CO<sub>2</sub> routes were solved. Note that the accumulated costs N<sub>2</sub>O and CH<sub>4</sub> are computed inherently in the analysis but they were not used as objective functions because their corresponding values are much lower in comparison to CO<sub>2</sub>. The results of the optimisation on the case studies are displayed in Figures/Tables 5.4.1, 5.4.2 and 5.4.3.

For the first case study, rail is an attractive mode to minimise the operational costs, energy and CO<sub>2</sub> emissions however it doubled the time it takes road (truck) to do the deliveries. Table 5.4.1 also shows that for intra-island distribution such as Auckland to Wellington, the usage of ship is quite competitive in terms of operating costs, but performs poorly in terms of time, energy usage and gas emissions hence may not be the most practical option for this kind of distribution.

The second case study (Auckland to Christchurch) shows that there are more incentives for using rail and shipping, due to the longer distances and the inter-island transfer. Shipping provides low-cost transport of goods while rail is once again the best mode for emissions-savings. The optimal route for energy is a combination of rail from Auckland to Wellington then shipping from Wellington Harbour to Lyttelton port in Christchurch.

On both studies, it is apparent that the only benefit of using road (trucks) is that it has lower total time of deliveries than other modes. We then contrast this with a case study of a distribution scheme from West Coast to Christchurch. This is another intra-island distribution however the movement of commodities is from west to east direction which is of smaller geographic distance and separated by a mountainous terrain. In this case, road is

the fastest and least costly route while rail is the best choice with energy and CO<sub>2</sub> as deterrence parameters. The use of coastal shipping for distribution of goods from West Coast to Christchurch performs poorly on all accounts which make it an illogical and impractical option which is probably due to the lack of accessible inland shipping routes between the two regions.



**5.4.1 : Scenario analysis of distribution from Auckland to Wellington**

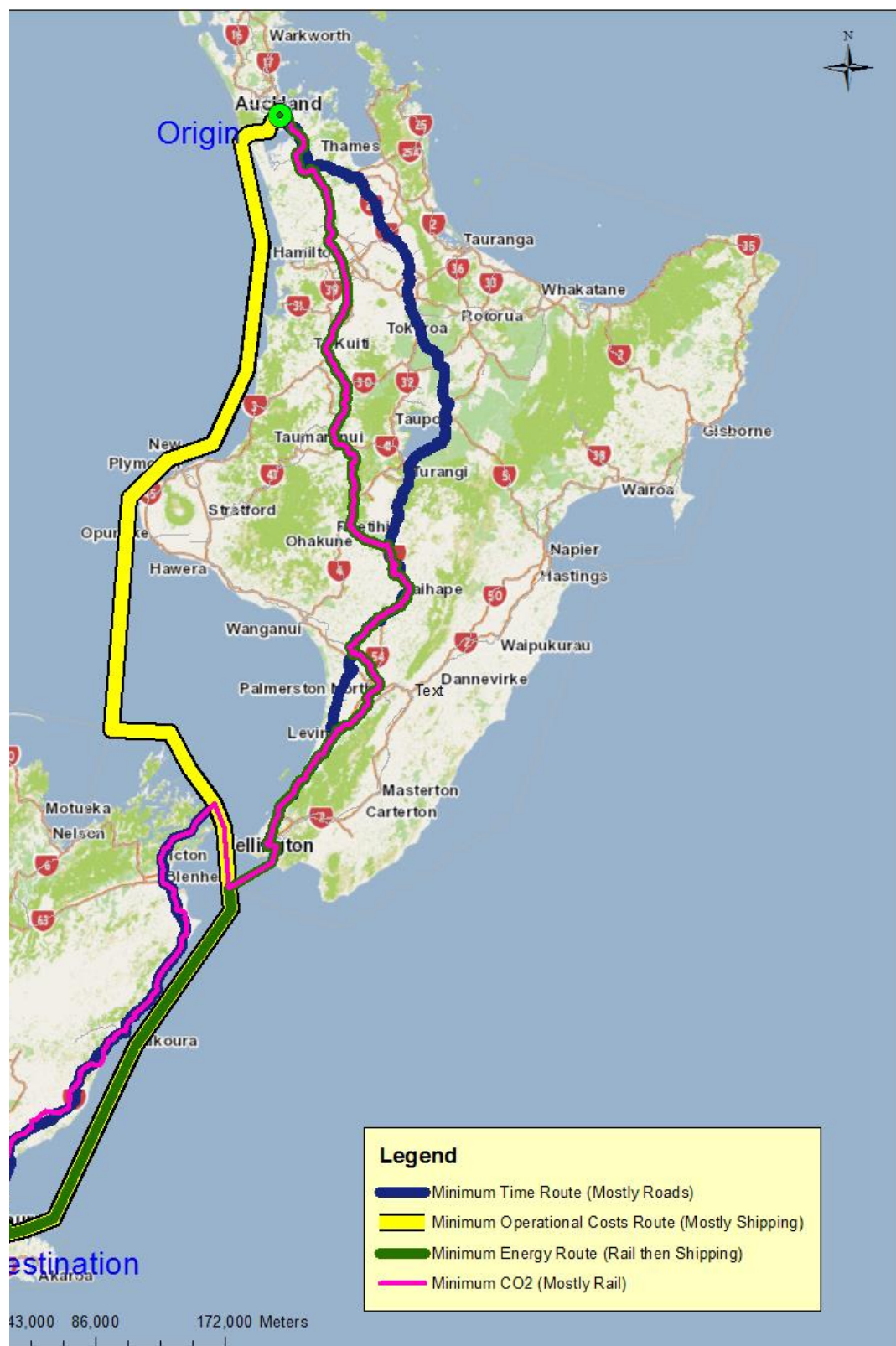


Figure 5.4.2 : Scenario analysis of distribution from Auckland to Christchurch



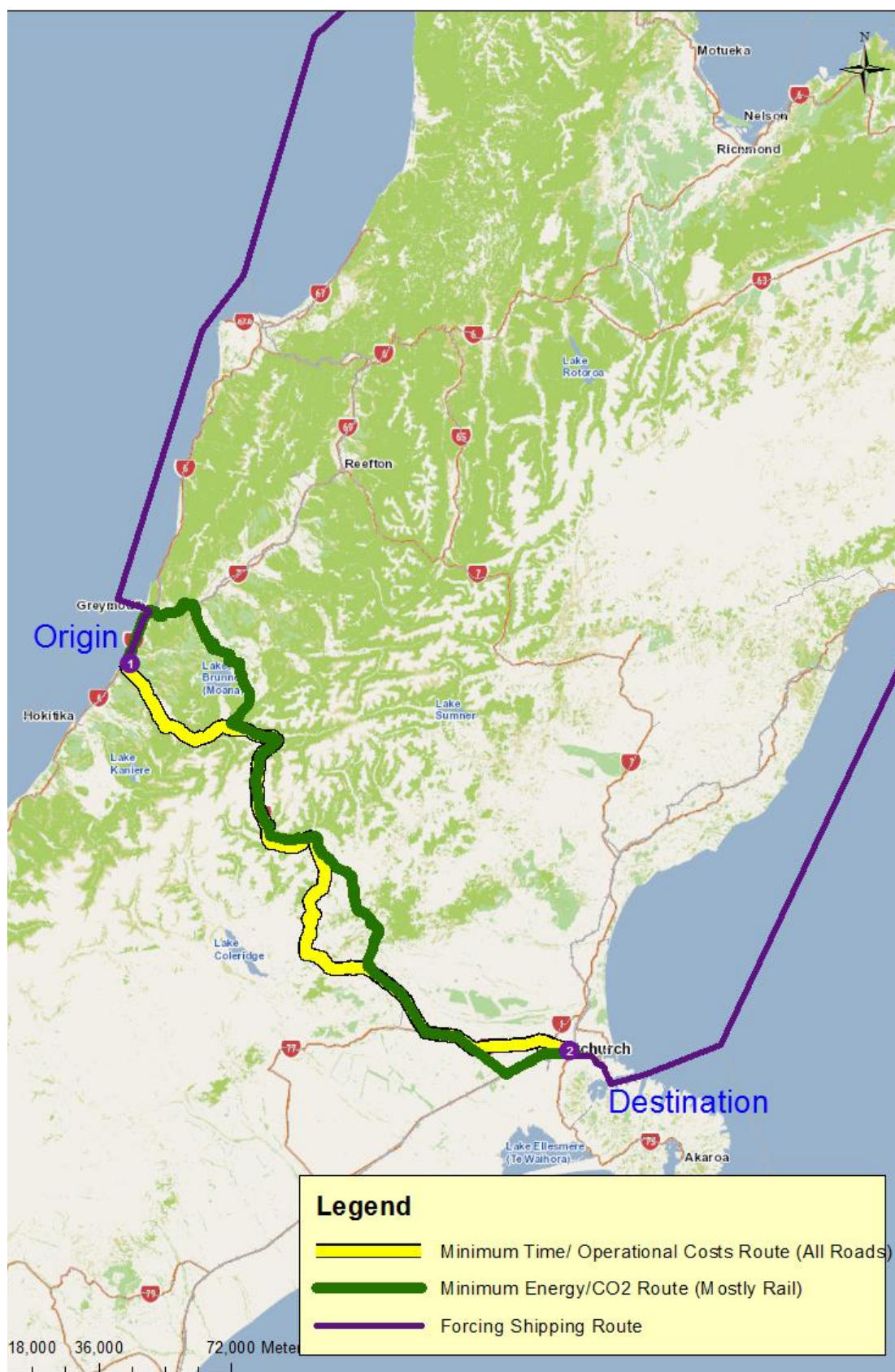


Figure 5.4.3: Scenario analysis of distribution from West Coast to Christchurch

**Table 5.4.1 : Results for NZIFN model runs from Auckland to Wellington**

Route	Primary Mode	Total Time (hr)	Total Operational Costs (\$)	Total Energy (MJ)	Total CO <sub>2</sub> (g)	Total N <sub>2</sub> O (g)	Total CH <sub>4</sub> (g)
Minimum Time	Road	6.9	2136	7866	3,442,957	179	404
Minimum Operational Cost/Energy/CO <sub>2</sub>	Rail	17.4	1411	4388	674,921	28	44
Forcing Ship	Ship	34	1440	5893	2,843,418	82	278

**Table 5.4.2 : Results for NZIFN model runs from Auckland to Christchurch**

Route	Primary Mode	Total Time (hr)	Total Operational Costs (\$)	Total Energy (MJ)	Total CO <sub>2</sub> (g)	Total N <sub>2</sub> O (g)	Total CH <sub>4</sub> (g)
Minimum Time	Road	21	3870	13488	5,963,913	296	687
Minimum Operational Costs	Ship	45	1969	8147	3,921,583	115	386
Minimum Energy	Rail then Shipping	38	2525	7545	2,164,468	73	190
Minimum CO <sub>2</sub>	Rail	37	2792	8108	1,715,420	64	135



**Table 5.4.3: Results for NZIFN model runs from West Coast to Christchurch**

Route	Primary Mode	Total Time (hr)	Total Operational Costs (\$)	Total Energy (MJ)	Total CO <sub>2</sub> (g)	Total N <sub>2</sub> O (g)	Total CH <sub>4</sub> (g)
Minimum Time/ Operational Costs	Road	2.4	751	2785	1,219,054	64	143
Minimum Energy/ CO2	Rail	9.4	894	1819	366,389	17	31
Forcing Ship	Ship	40	1826	7308	3,508,549	105	346

## 5.5 Results and Discussion

The algorithm presented in the previous section allowed us to determine the optimal mode given the deterrence parameter on the route required. The next step is to assess the current commodity flows and the potential of modal shift of these flows. The mode share of different commodities was discussed in Chapter 3.2, here we will investigate mode-shifting for some commodities which are already utilising either rail or shipping (which means the some form of existing infrastructure is already in place). Using the freight matrices of inter-regional distribution in the country (Paling, 2008), we selected commodities that are currently being distributed from Auckland to Wellington region by rail, and Auckland to Christchurch by shipping. This implies that the modes selected are both contestable and commercially contestable as defined in (Healey, 2009) and in Chapter 2.3.1 hence modal shift is considered a logical and achievable option. Note that some other commodities may be inherently unsuitable for mode shift due to compatibility of goods, container and vehicle type.

We then calculate the current costs of distribution using the current mode share and also with the road share arbitrarily decreased to some percentage. The percentage of mode shift chosen must be of realistic and attainable value.

For the Auckland to Wellington scenario analysis, the commodity chosen is aluminium and steel with 60,000 tonnes being moved annually from Northland/Auckland to Taranaki/Manawatu-Wanganui/Wellington region with road and rail having shares of 80% and 20%, respectively. Meanwhile for the Auckland to Christchurch analysis, the commodity chosen is Petroleum with 300,000 tonnes being moved annually from Northland/Auckland to Canterbury region with road and shipping shares of 75% and 25%, respectively (Paling, 2008). Note that both commodities selected are non-perishable items, which means that the timeliness of their deliveries is not crucial and benefits of other attributes of savings on operating costs, energy and emissions could be given a greater importance and preference.

The following tables show detailed calculations of differences in the deterrence parameters with the application of the hypothetical mode shift scenario. Table 5.5.2 shows that marginal savings are achieved on energy and greenhouse gas emissions with rail share increasing from 20% to 30%. Increasing rail share by 10% of the Auckland to Wellington route produced up to 5% savings for energy and 10% on CO<sub>2</sub> emissions. For the Auckland to Christchurch distribution of petrol, increasing coastal shipping share from 25% to 50% allows more than 20 million MJ or 11% savings. It also reduced CO<sub>2</sub> and N<sub>2</sub>O emissions by 9% and 18%, respectively.

The increased share of rail and shipping on these scenarios are not totally excluding road freight percentage but are conjectural values which may be feasible given the current infrastructures in New Zealand.

**Table 5.5.1 : Mode Share of the Auckland to Wellington distribution of aluminium and steel**

Commodity	Aluminium and Steel	Current Road Share 80%	Current Rail Share 20%	Hypothetical Road Share 70%	Hypothetical Rail Share 30%
Total Tonnes	60,000	48,000	12,000	42,000	18,000
Number of TEUs	4,286	3,429	857	3,000	1,286

**Table 5.5.2 : Costs of Distribution from Auckland to Wellington of aluminium and steel for the current Scheme vs. Hypothetical Scenario**

	Total Operational Costs (\$)	Total Energy (MJ)	Total CO <sub>2</sub> (g)	Total N <sub>2</sub> O (g)	Total CH <sub>4</sub> (g)
Current Road Costs	7,324,344	26,972,514	11,812,757,553	613,791	1,385,316
Current Rail Costs	1,209,227	3,760,516	578,407,297	23,996	37,708
<b>Current Total Costs</b>	<b>8,533,571</b>	<b>30,733,030</b>	<b>12,391,164,850</b>	<b>637,787</b>	<b>1,423,024</b>
Hypothetical Road Costs	6,408,000	23,598,000	10,334,871,000	537,000	1,212,000
Hypothetical Rail Costs	1,814,546	5,642,968	867,948,406	36,008	56,584
<b>Hypothetical Total Costs</b>	<b>8,222,546</b>	<b>29,240,968</b>	<b>11,202,819,406</b>	<b>573,008</b>	<b>1,268,584</b>

<b>Savings</b>	<b>311,025</b>	<b>1,492,062</b>	<b>1,188,345,444</b>	<b>64,779</b>	<b>154,440</b>
<b>Percentage of Reduction</b>	<b>4%</b>	<b>5%</b>	<b>10%</b>	<b>10%</b>	<b>11%</b>

**Table 5.5.3 : Mode Share of the Auckland to Canterbury distribution of petroleum**

Commodity	Petroleum	Current Road Share 75%	Current Shipping Share 25%	Hypothetical Road Share 50%	Hypothetical Shipping Share 50%
Total Tonnes	230,000	172,500	57,500	115,000	115,00
Number of TEUs	16,429	12,321	4,107	8,214	8,214

**Table 5.5.4 : Costs of Distribution from Auckland to Canterbury of petroleum for the current Scheme vs. Hypothetical Scenario**

	Total Operational Costs (\$)	Total Energy (MJ)	Total CO <sub>2</sub> (g)	Total N <sub>2</sub> O (g)	Total CH <sub>4</sub> (g)
Current Road Costs	47,682,270	166,185,648	73,481,372,073	3,647,016	8,464,527
Current Shipping Costs	8,086,683	33,459,729	16,105,941,381	472,305	1,585,302
<b>Current Total Costs</b>	<b>55,768,953</b>	<b>199,645,377</b>	<b>89,587,313,454</b>	<b>4,119,321</b>	<b>10,049,829</b>
Hypothetical Road Costs	31,788,180	110,790,432	48,987,581,382	2,431,344	5,643,018

Hypothetical Shipping Costs	16,173,366	66,919,458	32,211,882,762	944,610	3,170,604
<b>Hypothetical Total Costs</b>	<b>47,961,546</b>	<b>177,709,890</b>	<b>81,199,464,144</b>	<b>3,375,954</b>	<b>8,813,622</b>
<b>Savings</b>	<b>7,807,407</b>	<b>21,935,487</b>	<b>8,387,849,310</b>	<b>743,367</b>	<b>1,236,207</b>
<b>Percentage of Reduction</b>	<b>14%</b>	<b>11%</b>	<b>9%</b>	<b>18%</b>	<b>12%</b>

## 5.6 Conclusion

The New Zealand Intermodal Freight Network (NZIFN) is a concrete visualisation tool that investigates the benefits of shifting from long-distance road freight to less energy and emissions-intensive modes such as rail and shipping. The NZIFN model allows a trade-off analysis using different objectives functions such as minimising time, operating costs, energy and emissions.

Two hypothetical case studies were analysed in this paper namely a) Auckland to Wellington distribution of aluminium and steel and b) Auckland to Canterbury distribution of petroleum and the computations for both studies showed the potential savings of shifting a fraction of the total commodities moved from road to rail or shipping. The choice of these commodities is based on the intrinsic compatibility of the product type, container, vehicle as well as a non-perishability requirement.

The calculations take into account marginal values for modal shift due to possible infrastructure constraints. Even so, the calculations showed up to 11% reduction in freight energy usage and 10% in CO<sub>2</sub> emissions. Furthermore, modal shift also reduced operating costs by as much as 14%. Both of the commodities chosen were non-perishable and hence

timeliness of deliveries may be traded for energy and emissions benefits particularly as fuel supply decreases and emission reduction schemes raise the relative costs of trucking.

The results of the hypothetical analysis could be useful for policy-makers in decision-making process concerning proper investments for a sustainable freight system for New Zealand. By investing on infrastructures that would aid in the creation of an intermodal freight system for New Zealand, it is possible to build a system more resilient to rising fuel prices. The study also showed that modal shift is in line with New Zealand's commitment in combatting climate change through its New Zealand Emissions Trading Scheme.

## **Chapter 6: Last Leg Logistics Strategies**

This chapter investigates last leg logistics strategies in the supply chain by looking at truck flow patterns to urban areas, in particular its relationship with the retail sector. This is divided into two sections; the first being a general assessment of trucks on urban areas while the second is a micro-level focus on the retail sector. The latter is an investigation of the truck trip generation rates of different food distribution systems namely supermarkets, convenience stores, bulk food store and the Farmer's market. This is a novel concept as trip generation studies are aimed at identifying the impact of trucks on urban congestion, noise and pollution, safety to other motorists, pedestrians and residents, as well as the overall strain that the heavy vehicles put on the road network.

### **6.1 Heavy Vehicles in the Urban Areas**

In Chapter 2.5, the issues of urban freight and the importance of trucks in the economy are discussed. In particular, trucks are ubiquitous in metropolitan areas where the concentration of businesses and employments are found and thus are often described as the lifeblood of the economy. In spite of this, people still have the negative sentiment towards trucks owing to issues on traffic congestions, pedestrians and motorist's safety, damages on roads, amongst others.

As an illustration of this relationship, we provided a GIS-analysis of how truck rates are influenced by the presence of businesses and employments in a particular location and vice

versa. In other words, we would like to show whether trucks are actually essential features in these environments where business establishments and consequently the places of employment are found. Since our models deviate from the norm of studying freight economics, we use the number of definable businesses and employment counts in a unit area as proxies for economic levels of a specific area.

### **6.1.1 Data Sources and Methodology**

We use heavy vehicles data from the Annual Average Daily Traffic (AADT) derived from state highway monitoring and traffic data collection by the New Zealand Transport Agency (NZTA) (Wen, 2011). NZTA employs 103 telemetry sites located at 89 different geographic locations around New Zealand. Heavy vehicles are classified as those weighing over 3.5 tonnes and measured using weigh-in-motion (WIM) technology. AADT also presents the distribution of heavy vehicles kilometres travelled on the state highways revealing that majority of heavy vehicles are in the 100-400km (Wen, 2011).

From 2009 to 2010, there is an increase of 3.4% in heavy vehicles in the state highways compared to only 0.6% increase in the total number of vehicles. This trend signifies higher levels of economic activities for New Zealand, at the same time a major concern for transport engineers and urban planners.

This case study examines the heavy vehicle rates of 2009 at Christchurch city, the second largest city in New Zealand. To conduct our investigation, the geographic coordinates of the AADT data are requested from the NZTA office and encoded into ArcGIS as a shapefile (Wen, 2011).



The AADT shapefile is overlayed with Christchurch business and employment data counts of 19 different industry sectors including retail. See Appendix E for the complete list. The Christchurch business and employment geographic data is apportioned according to territorial authority units.

### **6.1.2 Results and Discussion**

To show the distribution of businesses and employments in greater Christchurch city, we used graduated colours with darker hues denoting higher counts of the attribute while lighter hues shows lower counts. The resulting maps, Figure 6.1.1 and Figure 6.1.2 are almost identical. The areas of the heaviest concentrations of business establishments and employments are in the Christchurch business district, Middleton, Sydenham and Islington districts. Other areas of business concentrations are in CBD's outlying suburbs such as Riccarton and Merivale and Marshland, Sockburn and Hornby North while relatively more employments than businesses are found in Fendalton, Yaldhurst and the small eastern suburb Chisnall.

In order to show the impact of AADT heavy vehicles in region, graduated symbols are used. For this case, graduated circles with sizes proportional to the number of trucks found in a given location symbolise the vehicle count. Majority of the heavy vehicles are recorded in Oppawa, Middleton, Islington, Russley, Yaldhurst, and Wigram. Except for the CBD where the AADT was not available, it can be deduced from Figures 6.1.1 and 6.1.2, that the polygons with the darkest hues also have large circles on top of them such as Middleton, Islington, Russley and Yaldhurst. However, the northern highways of Belfast and south eastern roads of Oppawa have heavier vehicle traffic compared to the number of

businesses and employments found. On the other hand, the district of Marshland with intermediate number of firms (majority of which are in the construction sector) have obviously fewer heavy vehicles found in its highway.

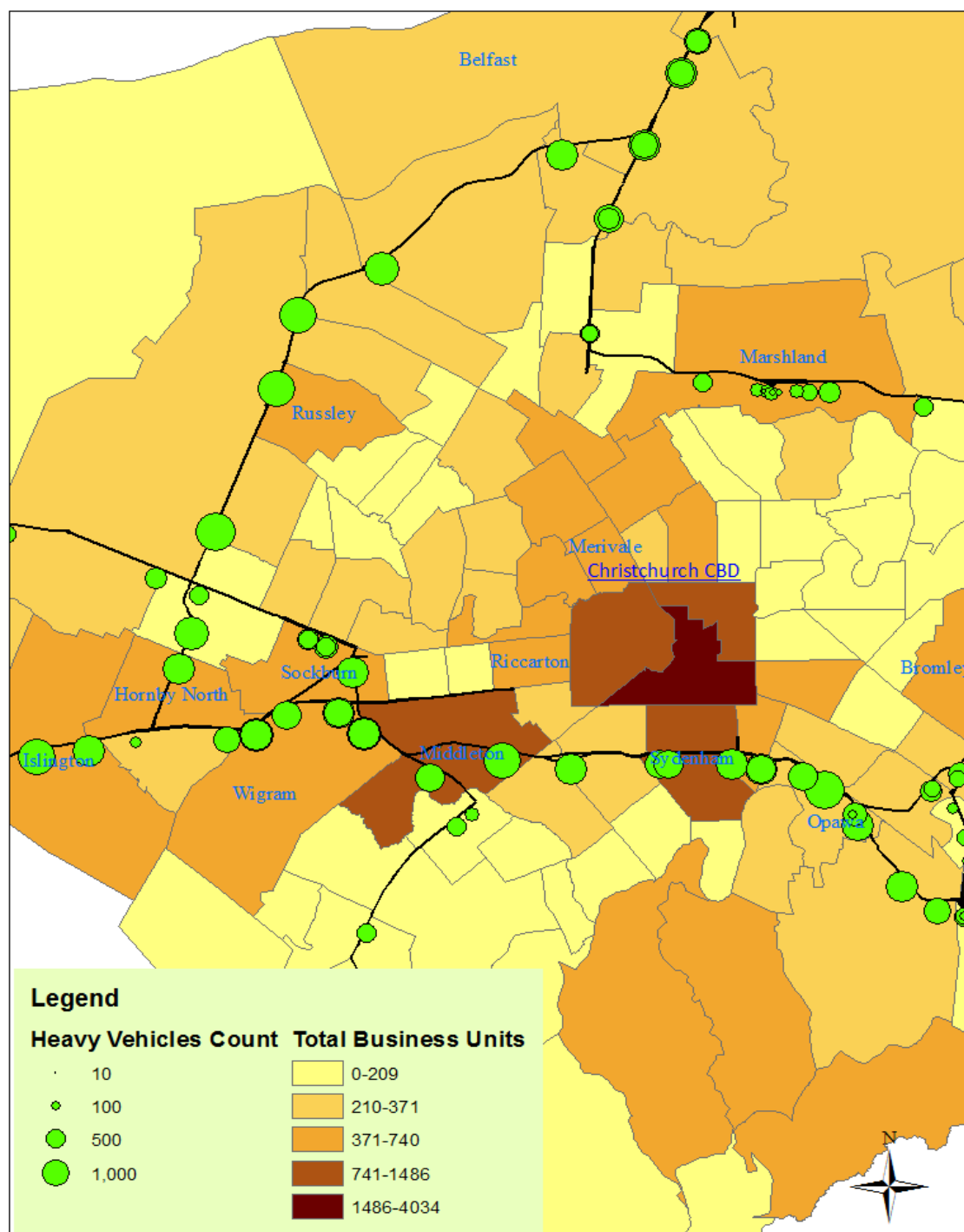


Figure 6.1.1 : Christchurch heavy vehicles count of 2009 vs. Total business units

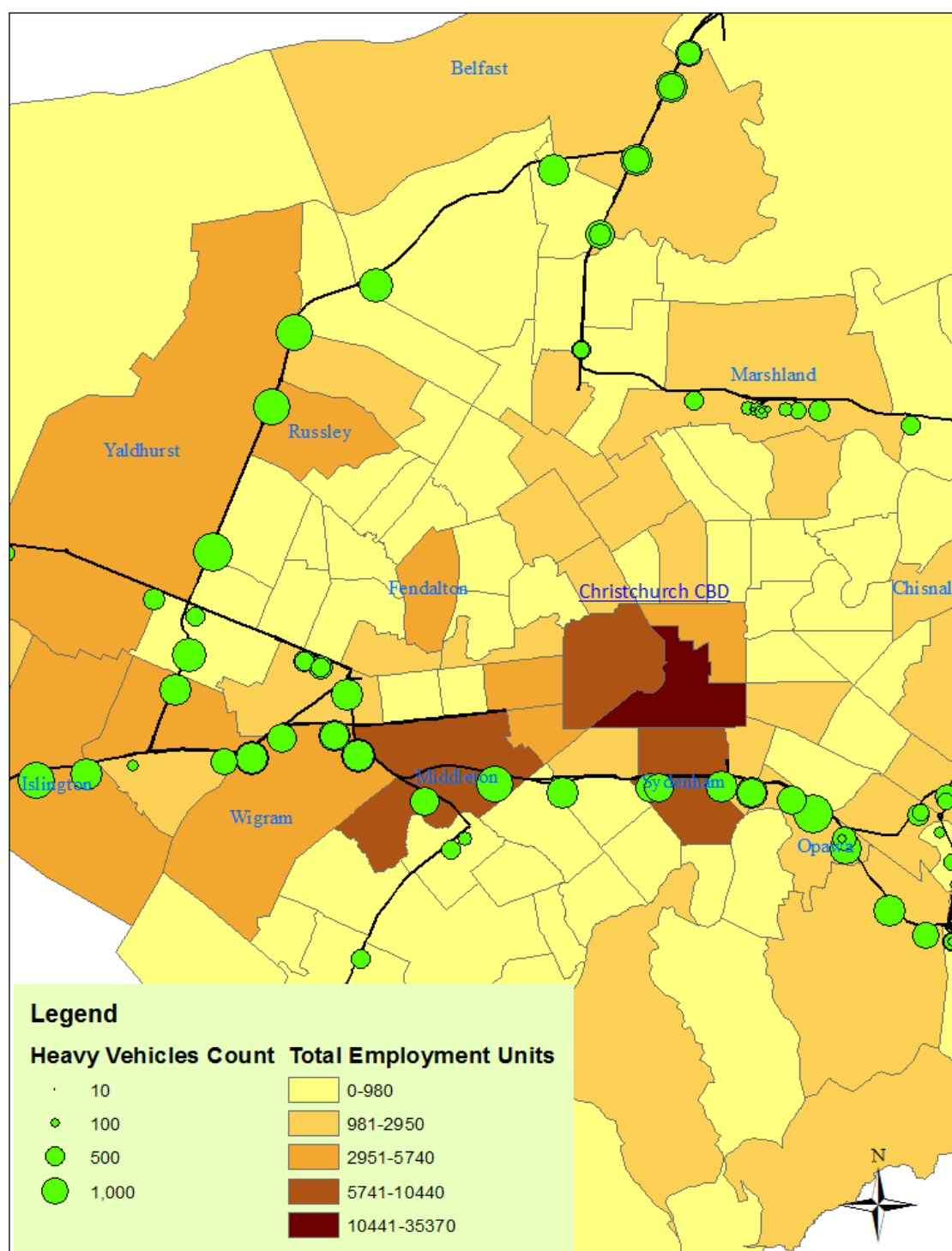
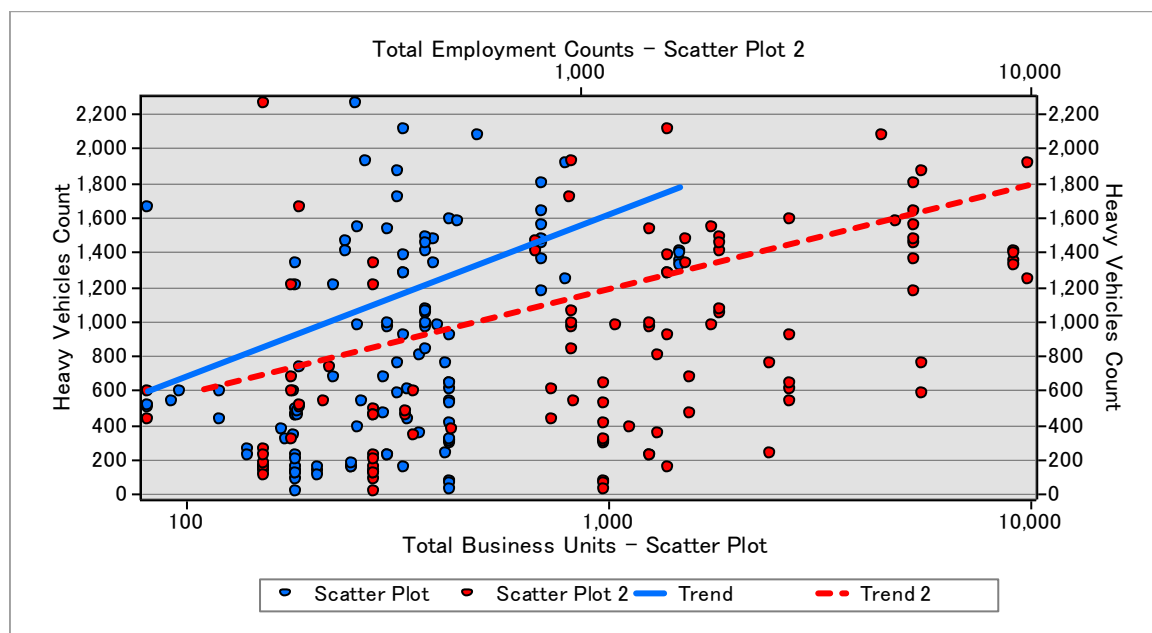


Figure 6.1.2 : Christchurch heavy vehicles count of 2009 vs. Total employment counts

Using scatter plots, we determine the relation between the business units and employment counts with the presence of heavy vehicles; that is we address the question, “Are the places with the most number of businesses and employments also the places where trucks are usually found?” And its direct implication, “Are trucks one of the sustaining elements of these businesses?”

As there are clearly more employment counts than business units, in which they roughly differ by a factor of 10, logarithmic plots of the total business establishments are used in order to show these two quantities together in a single graph. In Figure 6.1.3, we see that this correlation is not as strong as we have initially assumed. Though there is a clear trend that trucks and businesses/employments, the highest number of trucks are recorded in places/area polygons with fairly moderate number of businesses and employments. We discuss a possible explanation for this study in the succeeding subsection.



**Figure 6.1.3 : Christchurch heavy vehicle counts vs. Scatter plots of businesses and employment**

### 6.1.3 Limitation of the Study

The data from AADT only used state highway counts and not on smaller roads and network arteries through some of the denser business districts. One plausible explanation is that some trucks recorded in these highways are probably just passing by Christchurch to go to other regions or cities in Canterbury as seen in Figure 6.1.4 and is consistent with the AADT heavy vehicles kilometres travelled in the 100-400km range.

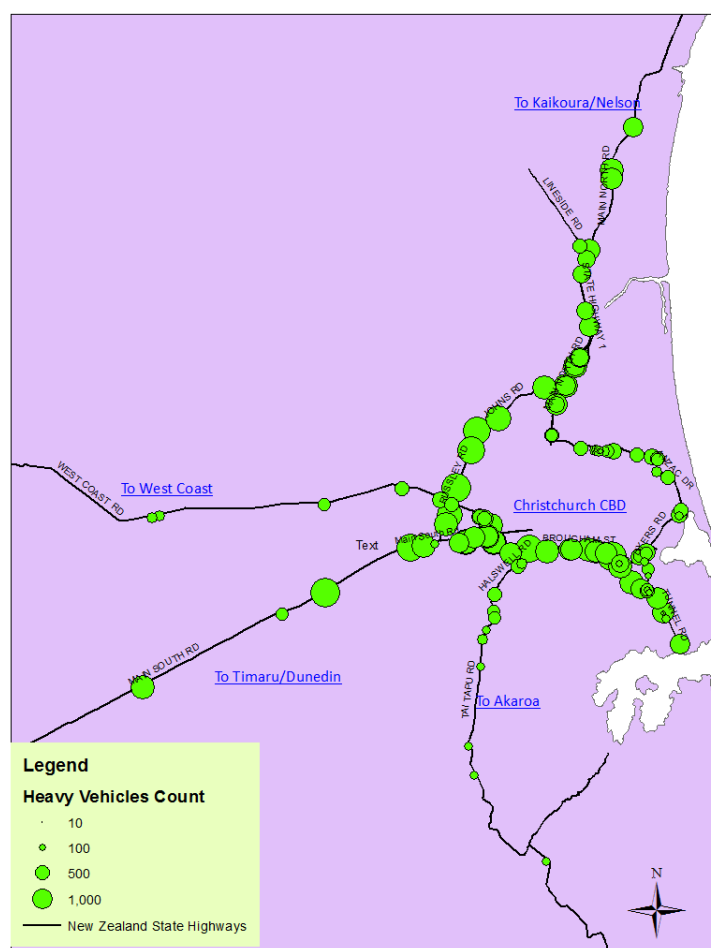


Figure 6.1.4 : Canterbury state highways heavy vehicles count

Hence, the analysis in Figure 6.1.3 showed more dispersed scatter plots and thus weaker correlations between the presence of establishments and employment and heavy vehicles recorded. Since AADT is an average of daily counts, it also fails to capture the details of deliveries at peak times or days when deliveries are much more frequent. The heavy vehicles classification of trucks above 3.4 tonnes is unable to make clear distinctions between the truck types found in these highways.

From here on, the study focuses on the retail sector. In Appendix E the maps and scatter plot graphs of retail sector business units and employment counts and its relation with AADT for heavy vehicles are presented. Heavy concentrations of business establishments for retail are found in the CBD, Riccarton and Sydenham, while jobs in this sector are also found in Hornby North, Northcote and Shirley East. See Figures E.1 and E.2 for more information.

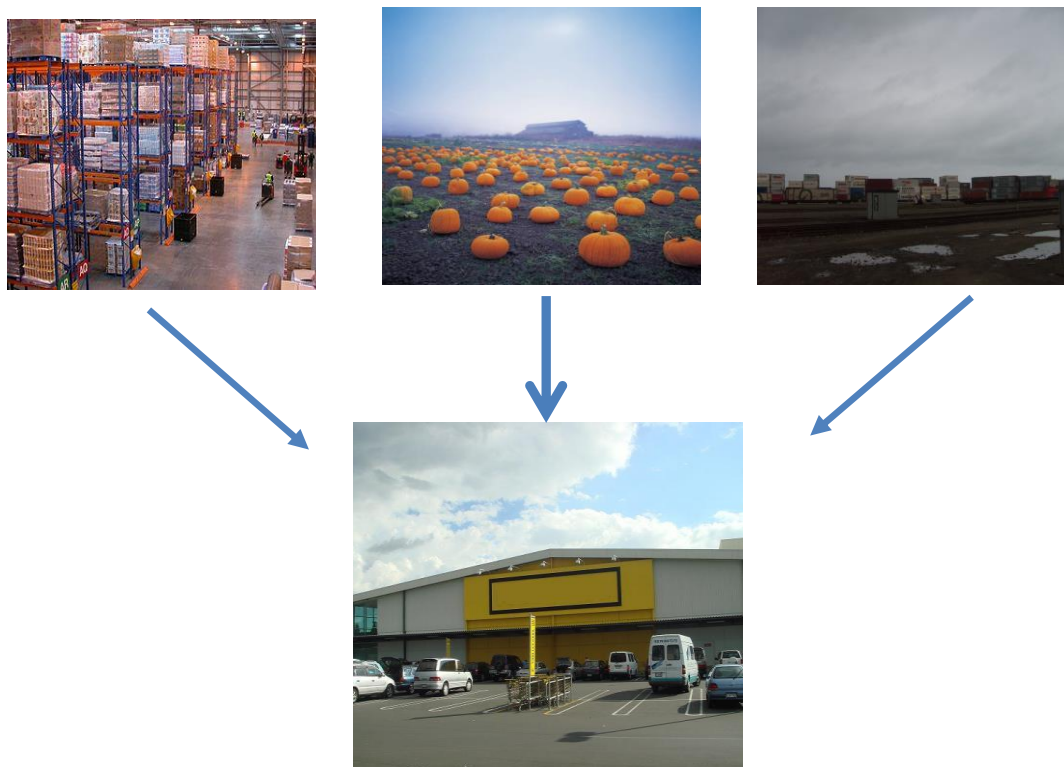
There is also clear trend of connection between retail businesses and employments with heavy vehicles but the scatterplots produced are also dispersed (Figure E.3). This observation brings us to the next stage of the study, a micro-level assessment of truck trips generated by retail establishment to regularly replenish their supplies and understand the real interdependencies of trucks and the retail sector. We chose this sector because retail, in particular the food sector necessitates more frequent and agglomerated deliveries of goods.

## 6.2 Last Leg and Truck Trip Generation

In Chapter 2.3, we were introduced with concept of freight trip generation. Since this case study is conducted to examine the last leg of the supply chain, we will henceforth use the term 'truck trip generation' to denote the number of freight-generated traffic or trips.

This case study is conducted in one town in New Zealand to understand the last link of the food supply chain from distribution centres, farms, rail yards or ports to the retail outlets/markets. See Figure 6.2.1. The objective of the study is to measure the number of daily truck trips needed by stores to replenish their supplies. In effect, we determine what factors have the biggest impact or influence on these truck trips and their distribution patterns. By looking at the truck trip rates and origin of the trip, the fuel consumption and fuel intensities are obtained. The actual results of this study is published on (Asuncion et al., 2012a).

A new parameter called 'Product Variation Score' is introduced in this study as a way to measure product ranges. If this product variation score is a strong indicator of truck trip generation rates, then this gives rise to the question of essentiality of these variability patterns in the freight delivery system.



**Figure 6.2.1 : Special link on the supply chain from DCs (or farms or ports) to the stores**

### **6.2.1 Data Sources and Methodology**

A survey and truck count study was conducted at eight participating food retail markets in one town in New Zealand in May 2011. The participants are 4 supermarkets, 2 convenience stores, 1 bulk food store and 1 farmer's market. Any information identifying the participant is withheld for privacy and confidentiality concerns. See sample privacy information sheet and consent form given to the participant in Appendix D.2.

#### **Store Classifications**

**Table 6.2.1 : Store classifications in the TTG study**

Supermarkets	<p>Large stores selling groceries and a wide range of products.</p> <p>The stores belong to huge chain of stores operating in the whole country. One characteristic of these stores is they offer</p>
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	a huge variety of products and could be a one-stop for all the customers' needs.
Convenience stores	Corner dairies and gasoline/service station with convenience market and characterised by long operating hours and sells a limited variety of products but they offer convenience to the customers.
Bulk food store	Stores carrying general goods plus specialised imported products whose main feature is that they sell items from bulk bins and allows customers to bring refillable containers to buy in-bulk products. They are typically larger than convenience stores but smaller than supermarkets.
Farmer's Market	Community of vendors, mostly farmers that sell their own local produce and were popular form of food distribution system before the industrialised and cheap fossil fuel era.





**Figure 6.2.2 : From top left, clockwise: Typical supermarket, petrol shop with convenience store, bulk food store, and Farmer's market in New Zealand**

### 6.2.2 Data Collection

The data collection for the study is broken down into 3 major steps:

1. Information about the physical and operational characteristics of the stores
  - a. Distribution of information sheets to prospective participants. Twenty information sheets were distributed and 8 stores agreed to participate.
  - b. A face-to-face interview is scheduled with the store managers. Questions included facility information, hours of operation, warehouse location, mode of deliveries, number of trucks expected on a typical day and garbage management.
  - c. With the consent of the store managers, the store dimensions are recorded using a laser measurer. The retail trading area and storage space are measured separately.
  - d. The number of parking spaces for each store is counted manually and noted whether that store is located inside a mall or a free-standing facility. For off-mall facilities, 70-90% of the parking spaces are allotted to store depending on the proportion of the size of the store to the mall floor area.

## 2. Manual Truck Counts

- a. For each store, two days of observation for truck counting is allocated except for the Bulk food store in which majority of the deliveries are on specialised days of the month. For each store, these days are chosen at random and must not include the minimum and the maximum delivery days which the store managers have cited on their respective interviews.
- b. Each truck arriving at the store is counted as 1 truck. The time of arrival and departure and whether the truck is unloading or loading (mostly garbage collection) is recorded.
- c. The truck type as well as the company information (whether it is a store truck, a freight company, or a direct supplier) is also noted.

## 3. Information about products and origin of loading and trip chaining

- a. When possible, the truck drivers were interviewed about the products they are unloading, the origin of loading, and other destination points. However due to time pressure of the driver's job, the answers on other delivery information were mostly vague and cannot be recorded properly.
- b. Riding with the truck drivers to determine the trip chaining was accomplished 4 times with one 3<sup>rd</sup> party freight company contractor.

### **6.2.3 Parameters for the Study**

This section gives a brief overview of the parameters used in the study and what kind of correlation is expected from them.

1. Retail trading area – the most commonly used parameter in gauging the truck trip generation of any industry. Assumes to follow a linear or logarithmic relationship with the truck trip generation rate.
2. Storage space – was typically combined with the retail trading area but on its own, this parameter could be a gauge of how frequent deliveries may be needed by the store. That is, a store with a bigger storage space may not necessitate as much deliveries as that of store with a smaller storage space.
3. Parking space – a proxy for demand and number of customers accessing the store by car.
4. Number of full-time equivalent employees (FTE) – is also assumed to be directly correlated with the truck trip rates as more employees mean more customers that need service.

These 4 parameters are often viewed as proxies of the economic activities of the stores. Ideally, the sales and revenue information would be the direct measure of the turnover of goods but is unlikely to be obtained due to privacy and confidentiality reasons.

5. Operation Hours – longer operational hours of stores may translate to higher turnover of goods and number of trucks attracted but is hypothesised to be a weak factor.
6. Product variation score – new factor that will be investigated in this study. It was suggested by (McCormack, 2010) to investigate this parameter to determine how high variation of products affects the truck trip rates. We hypothesise that higher product variation will yield a higher number of truck trips. (Here, 6 kinds of commodities are surveyed and the brands present at each store are tabulated. The

products chosen are bread, jam, honey, oil, eggs, and yogurt) and the total number of brands for each product is used to calculate the cumulative product variation score of each store. A high product variation score implies that a store has a wide range of choices for a specific product and includes some special brands. (See Table 6.2.3 for the computation of the product variation score)

A sample comparison of the product variations in supermarkets and convenience stores is illustrated in Figures 6.2.3 and 6.2.4.

7. Trip Length Distribution – distance from the origin of loading. We hypothesise that high percentage of trucks coming from a “local” origin of loading will have a strong correlation with the number of trucks attracted to a store.
8. Truck Type Distribution – classified the trucks into 3 major types: namely SMALL, MEDIUM, and LARGE (see Table 6.2.6 for details). We hypothesise that a high percentage of trucks that are small will also yield higher number of total trucks attracted to the store.

Note that parameters 7 and 8 will serve as the basis of the calculation of the freight energy of the stores.

#### **6.2.4 Results and Discussion**

This section presents a summary of the results of the data gathering and analysis of the parameters discussed in the previous section with the truck trip generation rates of the stores.

**Table 6.2.2 : Store coding scheme used in the tables and graphs**

S1 – Supermarket 1	S3 – Supermarket 3	C1 – Convenience Store 1	FM – Farmers Market
S2 – Supermarket 2	S4 – Supermarket 4	C2 – Convenience Store 2	BS – Bulk Food Store

**Table 6.2.3 : Computation of the product variation score**

	S1	S2	S3	S4	C1	C2	FM	BS
Bread	14	11	13	13	4	3	1	0
Jam	11	9	9	6	3	1	2	1
Honey	11	8	9	8	2	1	1	2
Oil	17	16	18	11	3	0	0	3
Eggs	8	9	8	6	2	0	0	1
Yogurt	19	14	17	19	1	0	1	1
<b>PRODUCT Variation Score</b>	<b>80</b>	<b>67</b>	<b>74</b>	<b>63</b>	<b>15</b>	<b>5</b>	<b>5</b>	<b>8</b>



**Figure 6.2.3 : Supermarket: High product variation of eggs**



**Figure 6.2.4 : Convenience Store: Low product variation of eggs**

Table 6.2.4 summarises the results of the survey/data gathering done in the study using the steps enumerated in Section 6.2.2.

**Table 6.2.4 : List of participating stores and its physical and operational characteristics and the observed truck counts daily average**

Establishment Code	Retail Trading Area (m <sup>2</sup> )	Storage Space (m <sup>3</sup> )	Number of Parking Spaces	Number of full-time equivalent employees	Product Variation Score	Operation Hours per Week	Observed Number of Trucks per day (Average)
S1	1800	413.8	165	115	80	98	24.5
S2	700	297	130	51	67	91	17.5
S 3	868	315.3	150	67.5	74	91	18
S 4	2669.6	1174.6	349	255	63	98	27.5
C 1	60	40	2	5	15	105	4
C2	100	12	8	6	5	105	5.5
FM	750	0	45	12	5	3.5	10
BS	183.52	43.3	30	8	8	52	1.1*

\*The Bulk Store Average of 1.1 per day is computed using the information given by the store manager on the trucks expected to come on a particular day in a typical month and this value may be not be as accurate as the actual counts for other stores. For the Bulk Store, a truck arriving once a week is calculated as  $1/5=0.2$  trucks per day using the assumption that other stores would only have regular deliveries on weekdays, that is 5 days a week.

The manual truck counts result shown in the last column of Table 6.2.4 gives an interesting result. The supermarkets average for this study in one town in New Zealand is 21.88 trucks while stores in the Puget Sound region, Washington have an average of 18 trucks per day



(McCormack, 2010) which could imply that stores in Washington (that are bigger) are using better freight logistic strategies than New Zealand supermarkets.

The next step is to determine the relationship between each of the parameter cited above with the observed average number of truck trips per day of the stores.

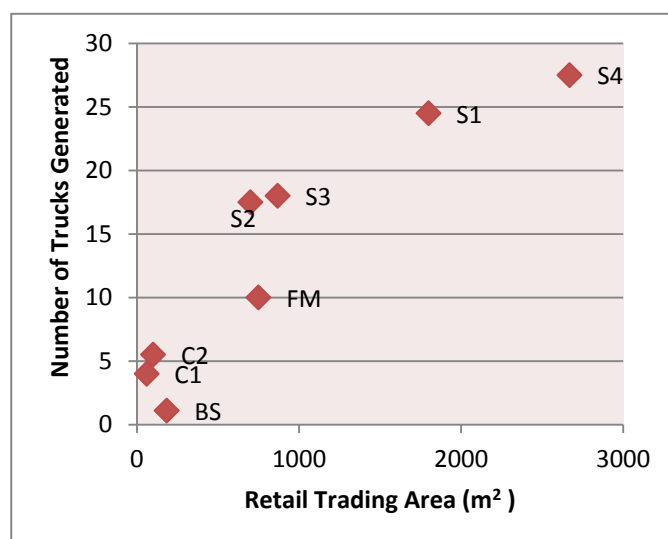


Figure 6.2.5 : Retail trading area (m2) and truck counts

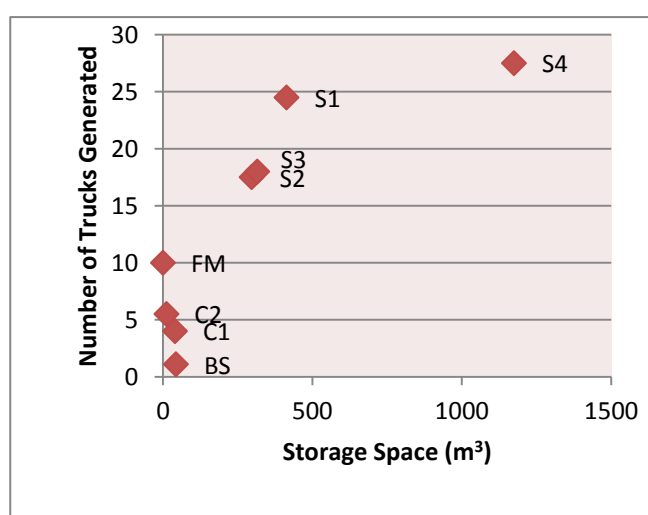


Figure 6.2.6 : Storage area (m2) and truck counts

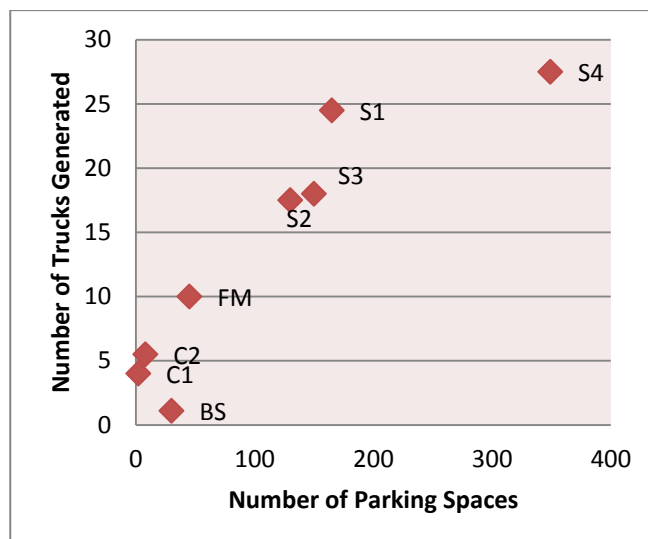


Figure 6.2.7 : Number of parking spaces and truck counts



Figure 6.2.8 : Number of FTE and truck counts

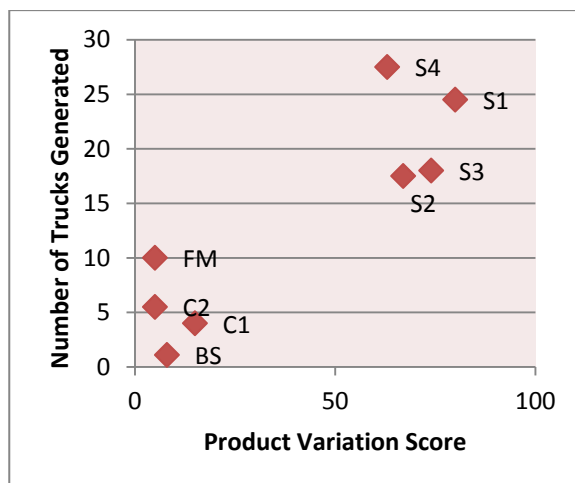


Figure 6.2.9 : Product variation score and truck counts

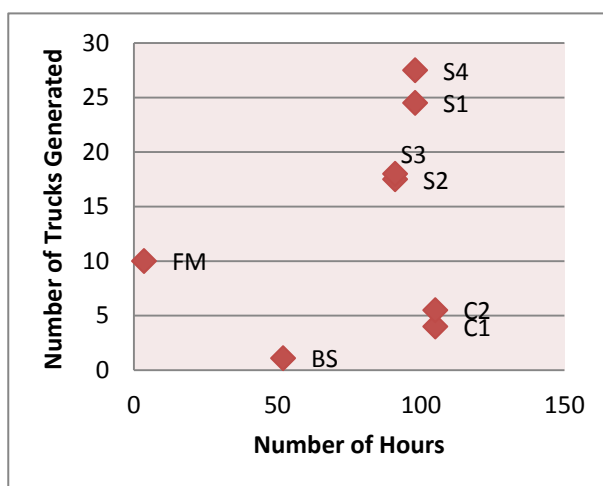


Figure 6.2.10 : Number of weekly operational hours of the store and truck counts

Figures 6.2.5-6.2.7 show that the parameters pertaining to the physical size of the store given by the retail floor area, storage space and number of parking spaces have a direct correlation with the number of trucks generated by the store. Figure 6.2.8 illustrates that the number of employees of a store is logarithmically related to the number of trucks with a high  $R^2$  value of 0.95. Figure 6.2.9 demonstrates the difference between the big stores

(supermarkets) and the smaller stores with respect to their product variation scores, as evident by the clustering behaviour on the graph. This implies that bigger stores have expected more product variability while smaller stores will not. Meanwhile, the number of weekly operational hours has no direct correlation with number of trucks attracted as shown in Figure 6.2.10.

The next sets of parameters to be studied are the trip length distribution patterns and the truck type distribution for each store shown in Table 6.2.5-6.2.7. The trip lengths are calculated based on the interviews with the truck drivers on their origin of loading which could be the farm, warehouse, distribution centre or rail/port depot.

We set the following classification/bins for the trip lengths:

**Table 6.2.5 : Trip length classification/bins**

Local	Origin of loading is $\leq 20$ km from the store
Regional	Origin of loading is 20 – 200 km away from the store
Long-haul	Origin of loading is $> 200$ km away from the store. Goods came from another region including those hauled from the other island, that is if the town is located in the South Island, then the goods came from the North Island (by truck), was transferred by Ferry, then trucked down again to the store.

The truck types are determined using the FHWA 13-bin vehicle classification wherein a rough re-classification is done for all observed trucks into 3 major types: “Small”, “Medium” and “Large” (Ministry of Transportation and Infrastructure, 2001).

**Table 6.2.6 : Truck type classification/bins**

Small	<p>Small trucks ranged from private cars, cars with trailers, pick-ups, and vans</p> 
Medium	<p>Medium trucks ranged from 2, 3, 4-axle single units, 2-axle tractor 1-axle trailer, 2-axle tractor 2-axle trailer, and 3-axle tractor 1-axle trailer.</p> 
Large	<p>Large trucks all those with a total of 5 or more axles.</p>



**Table 6.2.7 : Summary of the truck trip length and type distribution for each store**

	Local			Regional			Long-Haul			
Store	Small	Medium	Large	Small	Medium	Large	Small	Medium	Large	Total
S1	5	9.5	0	1.5	3.5	5	0	0	0	24.5
S2	4	7	0	0	2.5	3.5	0	0.5	0	17.5
S3	5	6.5	0	0.5	2	3.5	0	0.5	0	18
S4	6	7.5	1	0	5.5	7.5	0	0	0	27.5
C1	0.5	3	0	0.5	0	0	0	0	0	4
C2	1.5	3.5	0	0	0.5	0	0	0	0	5.5

FM	5	0	0	4	1	0	0	0	0	10
BS	0	0.6	0	0.15	0	0	0	0.35	0	1.1*

\*The Bulk Food Store Average of 1.1 per day is computed using the information given by the store manager on the trucks expected to come on a particular day in a typical month and this value may be not be as accurate as the actual counts for other stores.

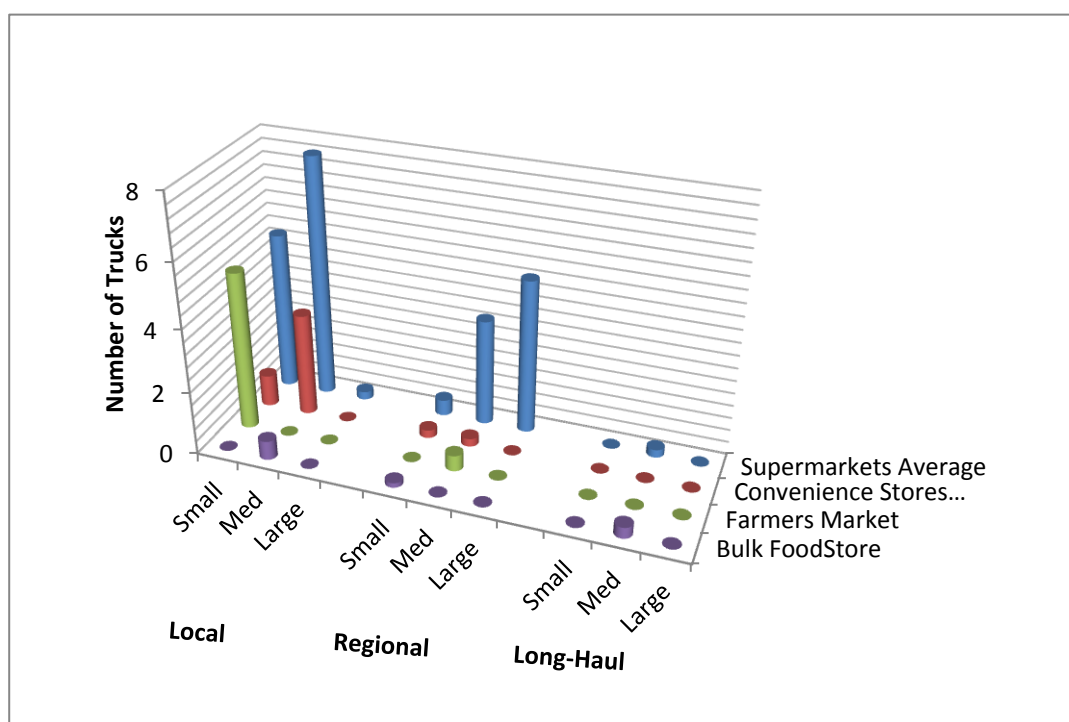


Figure 6.2.11 : Truck type and trip length distribution for the stores

Figure 6.2.11 shows that supermarkets utilises all types of trucks while convenience stores because they are smaller only uses small and medium-type trucks (getting their haul mostly

from a local warehouse), the farmer's market uses the vendors own vehicle, while the bulk food store uses small and medium-type trucks, half of which are long-hauled. The smaller trucks that come to the supermarkets are mostly vans carrying couriered-type goods.

The programming language R used specifically for statistical computing is utilised to produce the following correlation analyses between the input parameters and the truck trip generation rates of the stores. Table 6.2.8 shows that the variables producing the strongest correlation with TTG rates are the Retail trading area, Number of parking spaces and the Product variation score (in bold font). The last one is the novel variable included and this study and suggests that the more brands a store carries for a specific commodity, the higher the number of trucks it also needs to make the delivery. This inference is validated by the interviews with truck drivers to supermarkets citing that couriered-goods are mostly specialised items.

**Table 6.2.8 : Results of correlation analyses**

Parameter	R <sup>2</sup> value with Number of Trucks Generated	Correlation type
Retail Trading Area	<b>0.92</b>	Very strong correlation
Storage Space	0.84	Strong correlation
Number of Parking Spaces	<b>0.91</b>	Very strong correlation
Number of Full-time Equivalent Employees (FTE)	0.86	Strong correlation



Product Variation Score	<b>0.89</b>	Very strong correlation
Number of Weekly Operating Hours	0.30	No correlation
Trip Length Distribution Parameter (Percentage coming from Local Warehouse)	-0.46	No correlation (Negative)
Truck Type Distribution Parameter (Percentage of small trucks)	-0.07	No correlation (Negative)

Compared to the results obtained in (McCormack, 2010, Iding et al., 2002), our study suggests that size of store and employee number are good predictors of the TTG rates. In the Mc Cormack study, the only parameter with a strong correlation to TTG rates is the size of the store which is negatively correlated suggesting that smaller stores could actually attract more trucks. This phenomenon was not exhibited in our study suggesting that larger storage space does not decrease the number of deliveries.

We also highlight that the new parameter introduced in this study, namely the 'product variation score' is strongly correlated with TTG, implying that more trucks are needed for deliveries for stores carrying a wider range of brands for the same product. Supermarkets, known for carrying specialised brands in the products we sampled, may have higher product variation even for other items not in the study.

### 6.2.5 Computation of Freight Energy Intensity

The truck trip generation characteristics of stores is a result of complex logistical decisions on different levels of the supply chain and may be used by bigger firms and chains to look at optimal trade-off between costs, reliability and timeliness of the deliveries. However, as we have mentioned in the literature review in Chapter 2, this kind of analysis is basically done as part of their business strategy and may not take into account the vulnerabilities or susceptibilities of the system to rising fuel costs.

The methodology of the study which included the gathering of information of the truck type, origin of loading and interview with truck drivers enabled us to derive a method for determining an approximate measure or range of freight energy usage of the deliveries.

#### Method used to calculate the freight energy consumption and fuel intensity:

1. From Figure 6.2.6 (classification of vehicles), give an estimate of the worst possible mileage to the best possible mileage for the vehicles. A lot of factors may go into this computation including engine size, truckload, and engine efficiency based influenced by age, make, amongst others, drag, driver habits, and so on. Interview with some of the truck drivers are also used as a gauge in choosing this range:

**Table 6.2.9 : Estimated mileage range of vehicles**

SMALL	8 – 11 L/100 km
MEDIUM	14 - 25 L/100 km
LARGE	20 – 33 L /100 km

2. Take the median of the trip length distribution bins.

**Table 6.2.10 : Median distances of the trip length bins**

Trip Classification	Trip Range	Median
Local	0 – 20 kms	10 kms
Regional	20 – 200 kms	110 kms
Long-haul	200 – 1800 kms	1000 kms

3. Combine the information from Table 6.2.9 and Table 6.2.10 to obtain a range of the litres consumed for each trip bin and denote this as the best mileage (litres consumed) and worst mileage (litres consumed).

**Table 6.2.11 : Litres consumed for the deliveries based on the truck types and the trip lengths**

Median Trip Length (km)	10			110			1000		
Vehicle Type	Small	Medium	Large	Small	Medium	Large	Small	Medium	Large
Best Mileage (L)	0.8	1.4	2	8.8	15.4	22	8	140	200
Worst Mileage (L)	1.1	2.5	3.3	12.1	27.5	36.3	110	250	330

4. Use Table 6.2.7 (Summary of the Truck Trip Length and Type Distribution for each store) and Table 6.2.11 to compute the estimated number of litres consumed for the deliveries.
5. Determine the energy equivalent in mega joules (MJ) based on the liquid fuel conversion formula taking into account the Higher Heating Value (HHV) (Hoffstrand, 2008) (Hofstrand, 2008).

**Table 6.2.12 : Liquid fuel conversion using HHV**

Diesel	1 litre = 38.7 MJ
Gasoline	1 litre = 34.8 MJ

Performing steps 5 and 6 on our data of participating stores (that is multiplying each entry from Table 6.2.7 with the corresponding entry on Table 6.2.11) we obtain the total number of litres consumed using best and worst mileage estimates. Multiplying by the liquid fuel conversion yields the following:

**Table 6.2.13 : Total litres and energy consumed for the deliveries using the best and worst mileage assumption for the vehicles**

Store	Total Energy (MJ) Best Mileage Assumption	Total Energy (MJ) Worst Mileage Assumption
S1	7523	12583
S2	7682	13262

S3	7558	12959
S4	10333	17498
C1	348	546
C2	534	935
FM	1900*	2833*
BS	1980	3515

\*Note that Farmer's market vehicles being mostly private cars use gasoline instead of diesel.

The computation on Table 6.2.13 is an overestimation of the freight energy consumption as it assumes that the truck delivered only to one store from its origin of loading which only accounts for 19% of the total based on the driver interviews. If information on the number of delivery stops is known, then the energy consumption should have been divided amongst all stores on the driver's route.

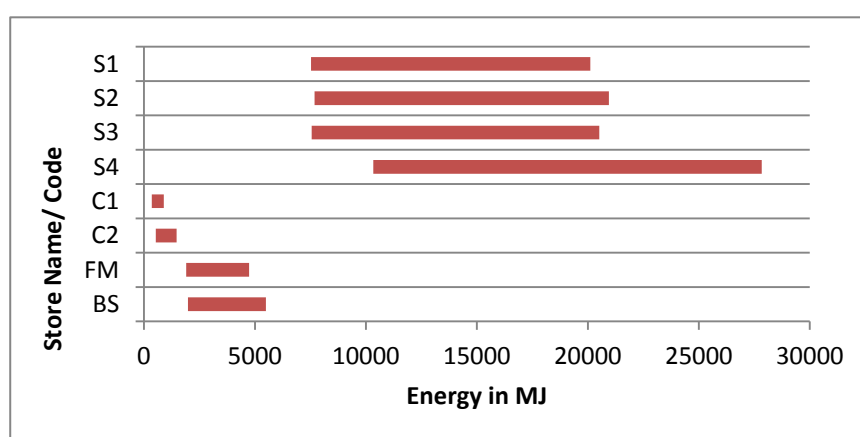
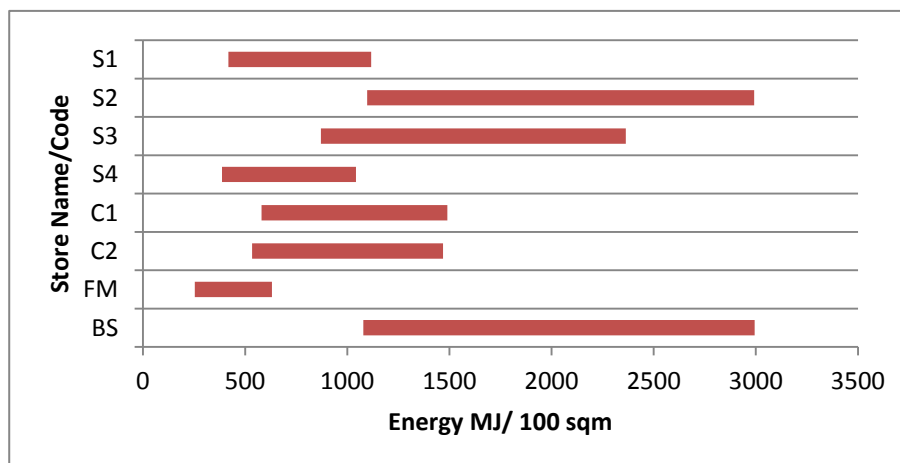


Figure 6.2.12 : Comparison of the freight energy usage of the stores

Figure 6.2.12 show that supermarkets with the highest TTG rates naturally also consume more energy.

6. The next step would be to give an approximation the fuel intensity of the deliveries to the stores. Ideally, fuel intensity is measured as total energy per unit of food delivered but since tonnage data are not available; the retail trading area is used as a proxy for this variable. The result of the correlation analyses showed that the retail trading area of the store is best gauge of the TTG. Also, as mentioned in Section III, it is a proxy for the customer based and demand of the store. Fuel intensity, in this study, is measured as the energy consumed per 100 m<sup>2</sup> of retail floor area.



**Figure 6.2.13 : Comparison of the fuel intensity of the stores**

Note that even though retail floor area is the best parameter influencing TTG rates, the dynamics of the Farmer's market of having relatively large floor area but very short

operational hours and smaller customer based may have skewed its result of the energy intensity calculations making it as the least-energy-intensive form of distribution.

Interestingly, supermarkets 1 and 4 with higher product variation scores and consequently higher TTG rates have lower fuel intensities which could be attributed to having bigger retail trading area. Both stores also didn't record any long-haul delivery which emphasised the importance of trip length distributions, which is a direct result of better logistical strategies employed by the stores.

On the other end of the spectrum, the convenience stores, in spite of having most of their deliveries from a local warehouse, scored relatively high fuel intensities owing to their high truck rates relative to their size (customer demand).

### **6.3 Conclusion**

Two different case studies were presented in this chapter. The first one dealt with general urban freight setting and aimed to highlight the correlations between trucks ubiquity and the presence of businesses and employments. Although there was a clear trend between these two elements, the correlation was weak, which may be attributed to the type of data available in our study.

The second study conducted is a survey on 8 stores in one town in New Zealand. The objective of the research is to capture the micro-dynamics behind the different distribution patterns of different kinds of stores in the country. The differences of the distribution models of these stores were reflected in the stark contrast of their truck-trip generation rates. Results revealed that the physical size of store is a strong determinant of freight

attracted to the stores. The operational characteristics, employment information and distribution patterns of the stores were also examined and included in the analysis.

The retail trading area and parking space of the stores present the strongest factor in determining the number of trucks generated but new parameters such as product variation and trip-length and truck-type distribution were also analysed. Product variation has a strong correlation with the number of trucks. This is due to the fact that more deliveries are needed for specialised brands that a store carries. Supermarkets owing to their larger customer based, shown by their bigger store dimensions, also attracts the highest number of trucks but has slight differences from each other which is highlighted by their product variation scores.

Meanwhile trip lengths and truck types showed no link with the number of trucks. These values were included in the study in order to calculate the freight energy consumption of the deliveries and the fuel intensity. The Farmer's market with all of its goods coming from local or regional farm may have the lowest fuel intensity amongst all participants but some factors need to be taken into account in the calculations such as trip chaining. Nevertheless, the results of the fuel intensity calculation could serve as a springboard for further studies for which logistical strategies in the last leg of the supply chain results in the least fuel-intensive distribution scheme.



## Chapter 7: Localised Production

The previous chapter compared the last-leg logistic patterns of different food distribution systems such as supermarkets, dairies, bulk food store and Farmers' markets. In the case of the Farmers' market, this last-leg of the chain is usually the total of the transport supply chain. Removing the links or shortening the supply chain is the common feature of localised food system. In this chapter, we focus on the system dynamics of and explore the characteristics of the Farmers' markets. In particular, we conduct a freight energy audit using concrete data traceability of the products of the market.

### 7.1 Overview

Localised food system is studied in the context of Farmers' markets. In New Zealand, Farmers' market normally operates 1 day a week for around 3-4 hours. The number of stalls and the type of goods being sold varies seasonally in contrast to the supermarkets (Asuncion et al., 2012a). Farmers' markets efforts are in line with sustainability and support for fair trade movements, however another primary purpose of the market is it serves as weekend community gathering location hence some stalls usually carry hot foods which are cooked onsite (Farmers' Market NZ Inc, 2012).

In Chapter 2.6, we learned that life cycle analysis (LCA) and food miles are two measures used to assess energy usage in the food supply chain. The LCA is a comprehensive, extremely complex and painstaking task in which accounting for long-term energy usage and impact to the environment results in possible errors accrued from estimations in the

calculations. On the other hand, 'food miles' only looks at the transported distance and is considered over-simplistic. The standard comparative model of local food systems with modern food systems is to evaluate and compare the energy intensities of different products (Wallgren, 2006, Saunders et al., 2006, Van Hauwermeiren et al., 2007).

Instead of choosing between the existing methods, we conduct a system-wide assessment of the energy intensity by providing a distinction on products which lacks the 'traceability' factor from the main suppliers to the market. Products in the Farmers' markets are distinguished using this traceability factor in which produced, meat, eggs, fish, honey are easily traceable while bread, pastries and hot foods are difficult to trace, and in which case there is a need to identify the origins of the products' ingredients. In some sense, our method may be viewed as a modification of the easier to calculate 'food miles' methodology but accounting for the actual product type and mode of transport used.

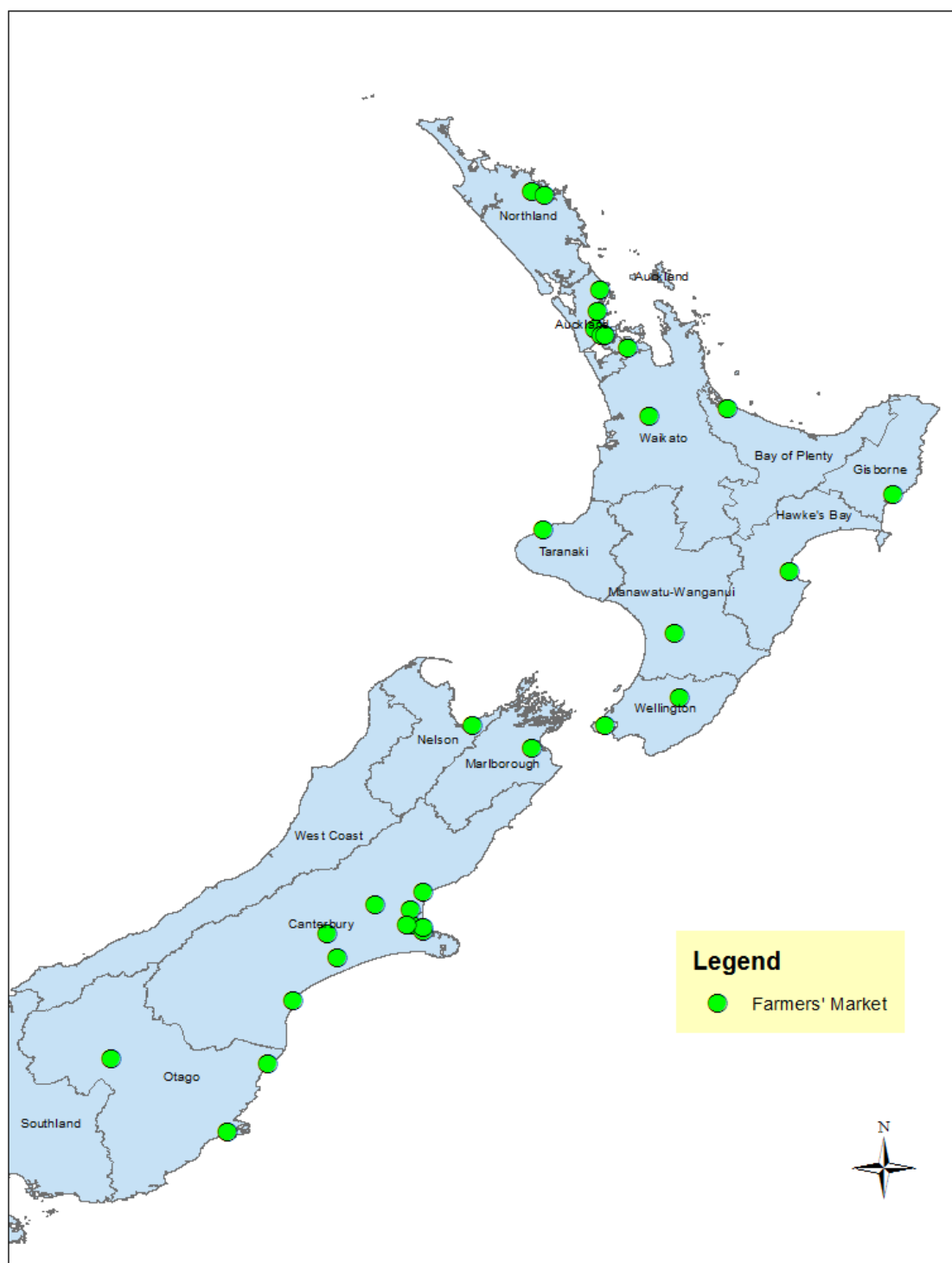


Figure 7.1.1 : Farmers' markets location in New Zealand

## 7.2 Methodology

The chosen method for the study is described as follows:

Each vendor in the market sells several products  $p_i$ 's and normally use a single vehicle  $v$ .

The origin is denoted by  $O$ , which could be farm/kitchen/bakery/butcher or the location where the food is loaded into the vehicle  $v$ . The destination  $D$  is the Farmers' market.

The energy use for freight transport  $E_{p,v}$  is given by the formula:

$$E_{p,v} = 2d_{p,v} \times f_v \times c_f \quad (\text{in MJ}) \quad (\text{Equation 1})$$

where

$d_{p,v}$  = network distance between origin  $O$  and  $D$ . This is the estimated distance travelled by the vehicle  $v$  to deliver product  $p$  from  $O$  to  $D$  (in km). The 2-factor accounts for the return trip which is expected to be empty running.

$f_v$  = fuel economy of the vehicle  $v$  (in litres/km)

$c_f$  = energy content of the fuel type (either petrol or diesel) (in MJ/litre)

Note that:

$$C_{Petrol} = 31.39 \text{ MJ/litre} \quad \text{and} \quad C_{Diesel} = 35.86 \text{ MJ/litre}$$

The freight transport energy intensity  $E_{int}$  (in MJ/kg) is a measure of the energy used to transport 1 kg of food to the Farmers' market given by:

$$E_{int} = \frac{\sum_{p,v} E_{p,v}}{\sum_p q} \quad (\text{in MJ/kg}) \quad (\text{Equation 2})$$

where

$q_p$  = Amount in kg of product  $p$  transported from  $O$  to  $D$ .

A distinguishing element of our methodology is the evaluation of traceability of products in the Farmers' market supply chain. As mentioned in the literature review in Chapter 2.7, the processes in the supply chain of the conventional supermarket system are obscured and hence there is lack of traceability of the products from primary producer to end-consumer. Our method aims to determine whether the same scenario holds true for Farmers market. By combining the traceability factor with other data collected from the survey, we perform a freight transport energy audit of the system then calculate the energy intensity.

### **Survey Description**

A list of Farmers' markets in New Zealand is given in the organisations' website (Farmers' Market NZ Inc, 2012). Their physical addresses were geocoded to produce Figure 7.1.1. Eight Farmers' markets were contacted via e-mail to join the study and 5 markets agreed to participate. See Appendix D.3 for a copy of the privacy information sheet and questionnaires.

The participants are denoted as FM1, FM2, FM3, FM4, and FM5. A list of the participants, number of registered vendors (Farmers' Market NZ Inc, 2012) are listed in Table 7.2.1 with each TA density class represented.

For FM1, FM2 and FM5, an onsite survey of the vendors was conducted. For FM3 and FM4, the market manager sent a list of the contact details of each vendor and each one was

contacted and asked to answer the survey. There are advantages and disadvantages for each data collection method. Onsite survey allows the surveyors to have personal interaction with the vendors and also obtain a better estimate of the amount of goods brought to the site. However, since the markets only operate for 4 hours maximum, some vendors opted out of the survey when they are busy with their customers. Phone surveys to the vendors require less resource but could take several days to be able to reach each one of them and some were also apprehensive to participate. Table 7.2.2 summarises the information asked to each vendor and how these information are used in the calculations.

**Table 7.2.1 : List of Survey Participants**

Participant Number	Number of registered stallholders
FM1	50
FM2	31
FM3	27
FM4	35
FM5	37

**Table 7.2.2 : Survey questions for the vendors of the Farmers' markets**

Questions for the vendors	Data usage	Problems Encountered
Product type being sold	Classifying the products allows the distinction between easily traceable items with those containing several ingredients.	Some vendors sell a variety of products, in particular those who are selling “hot foods” which necessitates further re-

		classification
Estimated quantity of products brought to the market	Used in Equation 2.	Most vendors only have a very rough estimate of the quantity of products they are selling however they are able to describe a corresponding volumetric measure for them.
Number and type of vehicles used (specify fuel type)	The number and type of vehicles are used to obtain the fuel economy and fuel consumption and are used in Equation 1.	Some vendors are reluctant to give information about the vehicle type and would simply mention that they drove their own car and fail to give more specifics. These cases were marked as private vehicles using petrol.
Origin <i>O</i> (Farm, bakery, kitchen, butcher) location	The origin <i>O</i> is used to calculate the network distance travelled by the vehicle using ArcGIS 10 and used in Equation 1.	Some vendors were not specific about the actual locations and the surveyors were required to confirm the information.
Specify if products require certain ingredients and state where the ingredients are obtained (if known)	This is the traceability factor of the products in which some goods may be locally made or cooked in the market itself but contains ingredients from a distant region.	Some products require many ingredients and with the time-constraints facing both vendors and surveyors, details on minor ingredients have been omitted.

The survey was conducted during the winter season and it was expected that there are not only fewer vendors but also lower volume of products sold. Hence the computation of the

freight energy intensity for the Farmers' markets in New Zealand may vary and may even decrease if the survey was done during the summer season. A summary of the data gathered from interviews with the vendors of the 5 markets is given in Table 7.2.3.

**Table 7.2.3 : Summary of data gathered from 5 Farmers' market locations**

Participant Number	Number of vendors interviewed	Number of vendors selling products without "other ingredients"	Total cumulative 2-way distance travelled by the vendors (km)	Average 2-way distance (km)	Estimated Energy Usage (MJ)	Estimated amount of food brought to the market (kg)	Estimated transport energy intensity (MJ/kg)
FM1	22	11	2954	134	10470	4351	2.41
FM2	12	8	704	59	2689	3910	0.69
FM3	9	6	438	<b>44</b>	1727	2555	<b>0.68</b>
FM4	11	8	1128	103	5421	1278	4.24
FM5	9	5	705	78	2703	2100	1.30

### 7.3 Discussion of Results

Survey results showed that 38 out of 63 surveyed vendors (or 60%) are selling items which do not contain other ingredients. However, some of these vendors have mentioned that they bought their raw ingredients from other vendors located in the same market yielding high traceability of the products in the market. For products which are easily traceable, the computation of the energy intensity is direct from the use of Equations 1 and 2, but for those that contain ingredients, the location of the ingredients were first determined (when possible) before plugging into the equations.



It is also worthwhile to note that the FM3 with the lowest average 2-way distance travelled by the vendors also yielded the lowest freight energy intensity, but the small number of participants in the study may not make this a statistically relevant conclusion.

The energy intensities of New Zealand's Farmers' markets are comparable to the values obtained in studies in other countries. In Belgium the average of 7 raw products yields a transport energy intensity of 5.25 MJ/kg (Van Hauwermeiren et al., 2007). In Sweden, 21 producers of 1 Farmers' market have an average of 2.8 MJ/kg (Wallgren, 2006).

Computation of the corresponding transport energy intensity for supermarkets using the method described above is a highly complicated task owing to the lack of information and obscurity along the supply chain.

## 7.4 Comparison with Supermarkets

To determine the energy intensity of the New Zealand supermarket system, aggregated data from government-commissioned reports are used instead of our surveying method for Farmers' markets. However, freight transport energy intensity  $E_{int}$  (in MJ/kg) is defined analogously as the measure of energy usage in transporting 1 kg of commodities to the supermarkets.

The annual freight tonnes moved for retail food industry is given in the report of Paling (Paling, 2008). In addition, values for the energy consumption for road freight transport of food sectors using both petrol and diesel fuel was provided in the EECA Energy Ends Use database (Energy Efficiency and Conservation Authority, 2007). Paling also provided a coarse level of disaggregation between supermarkets with "other retail food" industry

wherein 76% of total sales for retail food belong to the supermarkets (Paling, 2008). Hence we used 0.76 as a multiplier of the total tonnes and road freight energy of retail to obtain the values for the supermarkets. The computations are as follows:

Estimated tonnes moved by supermarkets (Paling, 2008) :

$$(7,400,000 \text{ tonnes} \times 0.76) = 5,624,000 \text{ tonnes}$$

Estimated road freight energy used by supermarkets (EECA, 2010-2011):

$$(605,236,000 + 473,766,000) \times 0.76 = 820,041,520 \text{ MJ}$$

Converting from tonnes to kg and applying the Equation 2 yields:

$$E_{\text{int}} = E/q = 0.15 \text{ MJ/kg}$$

This value for the energy intensity of supermarkets in New Zealand is much lower than the energy intensities of the surveyed Farmers' markets. The underlying reason for this is probably due to the higher volumes of goods moved and the efficient logistical strategies such as the use of distribution centres and freight consolidation which is the second key indicator in the study. Non-food items delivered to the supermarkets were also factored in the calculation.

## 7.5 Farmers' Markets Potential for Freight Consolidation

This section describes a hypothetical simulation of freight consolidation in the local level. It is a framework to investigate ways for the Farmers' market system to be more efficient and

apply the logistical strategies of the conventional system while preserving the small scale and independent nature of the farms and the market (Jog, 2010).

Assume 20 vendors selling 200kg of food. From Table 7.2.3, the average 2-way distance travelled by the vendors to the market is 94km. The model randomly populates a map with 20 food locations such that the average 2-way distance of these locations to the market is 94km. Simulate the use of 1 van for each delivery with fuel economy  $f_v = 10\text{L}/100\text{km} = 0.1\text{L}/\text{km}$  and running on diesel (fuel content  $C_{\text{Diesel}} = 35.86 \text{ MJ}/\text{litre}$ ). Each truck drives a return-trip from its farm to the market to deliver the goods as illustrated in Figure 7.5.1. The values obtained in this model run are summarised in Table 7.5.1.

The trip chaining model is as follows: Instead of having each vendor drive from their respective origins  $O$  to the market, the model simulates the use of 3 light lorries/trucks with an average payload of 8.5 tonnes,  $f_v = 20 \text{ litres}/100\text{km} = 0.2\text{L}/\text{km}$ , also running on diesel. The goal is to find the most optimal trip chain for the trucks loading from the farm locations. Apply the classical vehicle routing problem (VRP) (Ravindran, 2009) and implement the model using ArcGIS 10 with the Farmers' market as the starting and ending points of each truck as illustrated in Figure 7.5.2. The corresponding fuel consumption results were shown in Table 7.5.2.

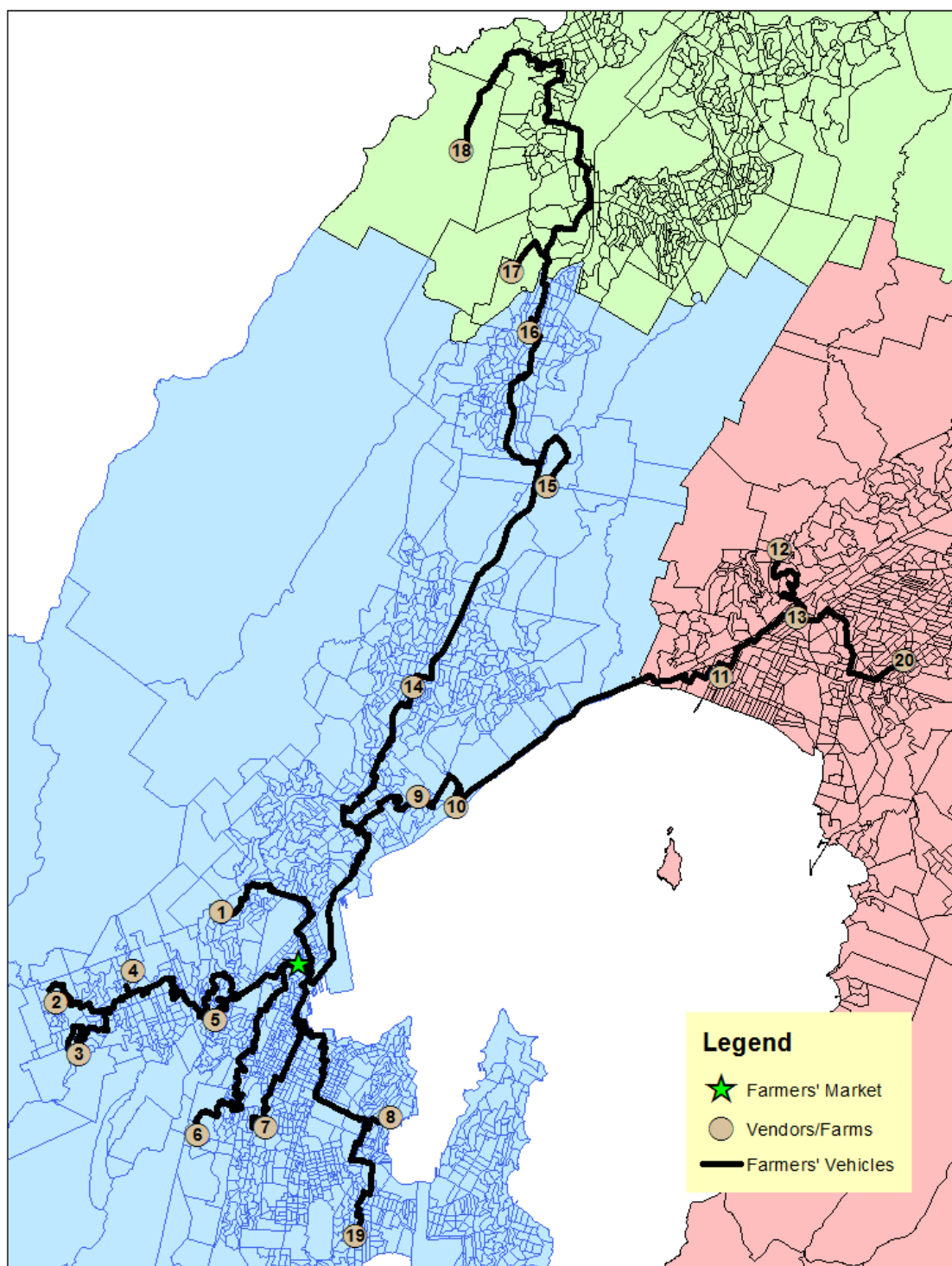


Figure 7.5.1 : Farms/Vendors delivering to the Farmers' market without VRP

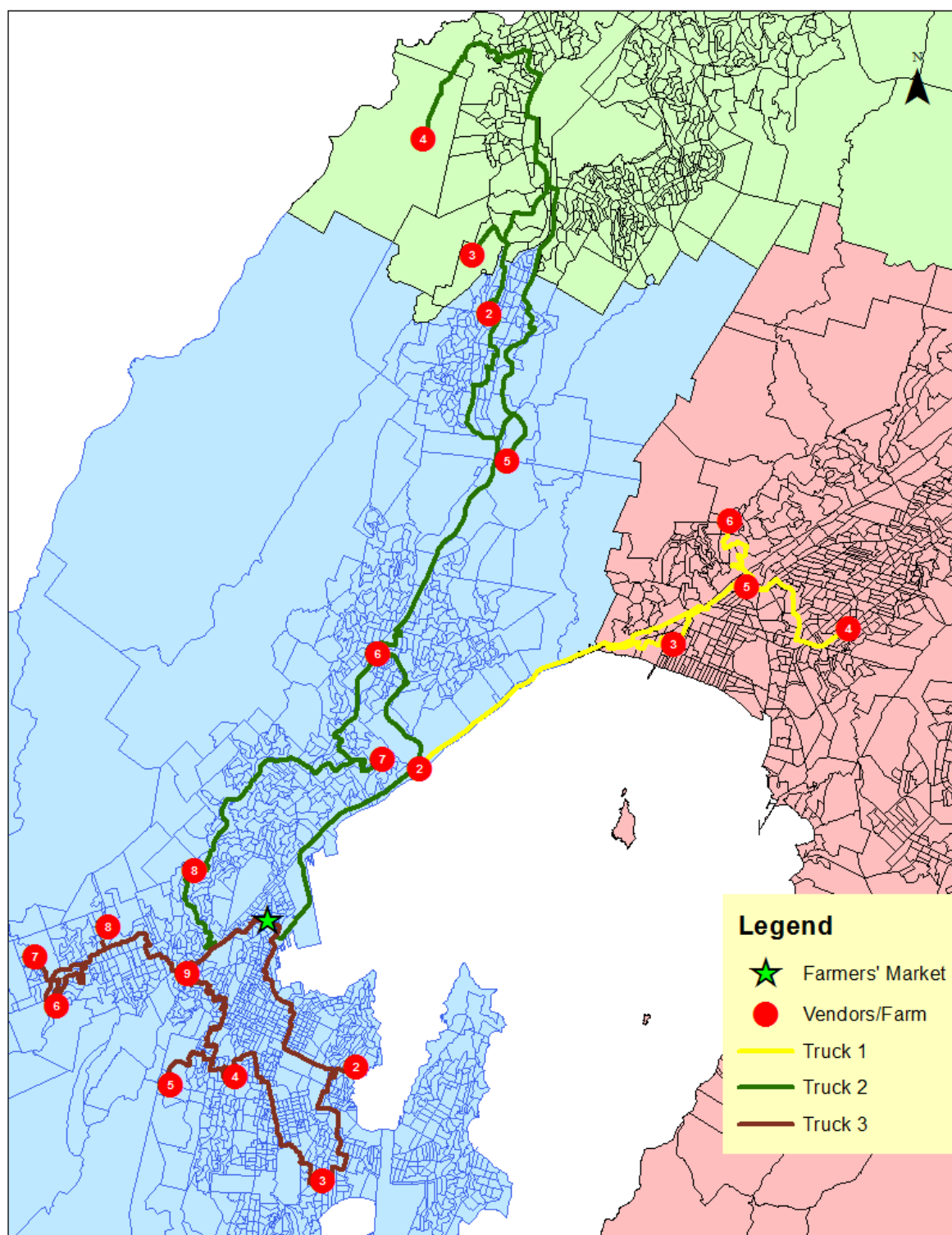


Figure 7.5.2 : Farms/Vendors delivering to the Farmers' market with simulated VRP

**Table 7.5.1 : Hypothetical model parameters without VRP and freight consolidation**

Number of vendors	Total 2-way distance (km)	Fuel economy $f_v$ multiplier (litres/km)	Energy content $c_f$ multiplier (MJ/litre)	Total energy usage (MJ)	Total food brought to the market (kg)	Transport energy intensity (MJ/jg)
20	1880	0.1	35.86	6752	4000	<b>1.69</b>

**Table 7.5.2 : Hypothetical model parameters with VRP and freight consolidation**

Truck	Number of Farms Visited	Total round-trip distance travelled (km)	Fuel economy $f_v$ multiplier (litres/km)	Energy content $c_f$ multiplier (MJ/litre)	Total energy usage (MJ)	Total food brought to the market (kg)	Transport Energy Intensity (MJ/kg)
Truck 1	5	114	0.2	35.86	818	1000	
Truck 2	7	182	0.2	35.86	1305	1400	
Truck 3	8	153	0.2	35.86	1097	1600	
Total	20	449			3220	4000	<b>0.81</b>

We observe that the use of VRP dramatically reduced the total distance travelled by the vehicles combined from 1880 down to 449 km. The energy intensity using this model is 0.81 MJ/kg which is almost a 50% reduction in the energy intensity without trip chaining freight consolidation (1.69 MJ/kg). However, this value is still much higher than the energy

intensity of the supermarkets as we have shown in the calculations in the previous section (0.15 MJ/kg).

The reason is still the large volume of goods distributed and higher utilisation of the capacity of the vehicles in the conventional supermarket system. The limited opening times of Farmers' markets in New Zealand clearly signify that they are still a niche market for weekend gatherers which reduce its potential for freight consolidation.

Another dilemma arising from this freight consolidation model is the logistics of how farmers will get to the market themselves. The vehicle chosen in the model is a light truck or lorry with a payload of less than 10 tonnes. In the vehicle routing model, each truck visits and takes goods from 5-7 farms. Given that at least two vendors would come from each farm, it would not be possible to fit in all 12 people plus the commodities inside a small truck.

One possible solution for this problem is for the farmers to assign a roster of vendors for a given day. Hence, farmers take turns in selling the goods for their colleagues who are not present at the market on a particular day. For this scheme to work out, an overseeing body is necessary to ensure transparency and integrity of the operations and accounting of the sales.

However, this approach would contradict the core principle of 'social embeddedness' of the local food system wherein consumers have direct and face-to-face interaction or personal communication with their food producers. The Farmers' market brand hinges on this involvement of food producers in entrepreneurial activity which connects them with the consumers. Moreover, even though it is beyond the scope of our research, this concept

of embeddedness is hypothesised to be a motivational factor for consumers shopping at the Farmers' markets.

The model presented in this section is not a predictor of the logistical strategies of the markets. It also does not account the economic feasibility and physical viability of the scheme proposed. However, it is a visualisation and quantifying tool in determining how to reduce freight fuel intensities of the Farmers' market system by employing logistical techniques similar to the supermarket system.

## **7.6 Conclusion**

We explored the characteristics of the Farmers' markets and compared it with the traditional supermarket system, in terms their differences in product traceability. This technique is called a 'freight energy audit' and measures the fuel intensity of the system.

The low volumes sold, lack of freight consolidation, and empty running return trips makes the Farmers' market more fuel intensive than the supermarkets in New Zealand. Applying logistical strategies such as the vehicle routing problem; trip chaining and consolidation of freight reduced the total combined distance travelled by the vehicles as well the freight energy intensity of the Farmers' markets. However, given the low volumes of goods sold at the market, the energy savings does not make the system more efficient than the supermarkets.

Freight consolidation also presents a challenge in how to maintain the social embeddedness in the Farmers' market. Given that the logistical strategy will prevent some farmers from being present at the market, freight consolidation may contradict the notion



of food producers interacting with end-consumers and may be unattractive to its current niche market. User preference is beyond the scope of this research and thus the embeddedness aspect of the market was only partially discussed.

## Chapter 8: Active Mode Access of Potential Customers

The final stage in determining the geographic adaptive potential of the freight transport and production system is to provide a measure for the access of customers to the products. In this case, the locations pertain to supermarkets and Farmers' markets, places where commodities are readily available and sold by the retailers.

### 8.1 Overview

The survey results in Chapter 6.2 of the Farmers' market indicated the presence of 45 parking spaces for customers of the market. This figure is much smaller than the supermarkets' average which is almost 200 spaces; however this is relatively high given that the volume of goods sold at the Farmers' market is significantly less than supermarkets.

Since we did not conduct any interviews with the customers nor assume anything about customer motivation of shopping at the market, the only indicator that customers drive to the market to procure their goods is gauged by the size of this parking lot.

Instead of determining how many customers are driving to the stores, we want a geospatial measure to evaluate how many of these customers *can* actually walk to the stores. For clarity, we determine how many customers and households are within 2-km away from a particular store, and thus have walking or biking access to that store.

The 2-km impedance factor is a reasonable distance for both walking and biking. Walking or biking to the stores is assumed not to consume any fuel. Of course, biking to the store

will take significantly shorter time than walking; however it may also present some challenges such as skill, presence of bike baskets for shopping, having small children and other safety concerns. Hence, to keep things impartial, we choose the distance parameter instead of a time parameter as impedance factor in the network.

The model aims to compare number of people and household that are within 2-km away from a supermarket or Farmers' market and this measure is termed as "Active Mode Accessibility" (AMA) introduced in the paper of Rendall et. al (Rendall et al., 2011, Rendall, 2012). It is defined as a gauge of the proportion of activities that can be reached by active modes, given the population demographics of a given area. Vicinities with high AMA indicates greater resilience to fuel price increases and greater transport system energy efficiency, otherwise it has low AMA.

To calculate the AMA of the stores, we use the ArcGIS concept of 'service area' which is the region of a specified impedance factor from or to a facility encompassing the accessible network of roads or streets (ESRI, 2012). Service area of a supermarket is also called as the supermarket sweep and includes all streets or roads that can reach the facility within a specified distance or time. It is a measure that evaluates access of the residents to the supermarkets (ESRI, 2012).

A simple illustrative example is given in Figure 8.1.1 showing the 2-km service area for a store in pink polygon, or the buffered 2-km zone from the store. For clarity, we have to emphasise that the distance discussed here is the network distance instead of geometric distance (otherwise, the service area will be a circle with centre at the store and radius of 2 km). The network distance of household 1 to the store is 1.25 km and it is located inside the 2-km area sweep. In contrast, household 2 is 3.16 km away from the store hence it is

located outside the area sweep. In our model, household 1 is described to have AMA to the store, while household 2 does not have AMA. The modelling assumption is that household 2 requires resorting to another mode of transport to the store. This alternative mode of transport would probably consume fuel directly, such in the case of driving a private vehicle, or indirectly such in the case of public transport.

Note that it is possible that even though household 2 does not have AMA to this particular store, it could have AMA to a different store. Likewise, it is possible for a household to have AMA to more than 1 store, as these service areas may overlap. In this case, we make no assumption as to which store a specific household may choose as this depends on their own preference, prices of goods at the store and other factors.

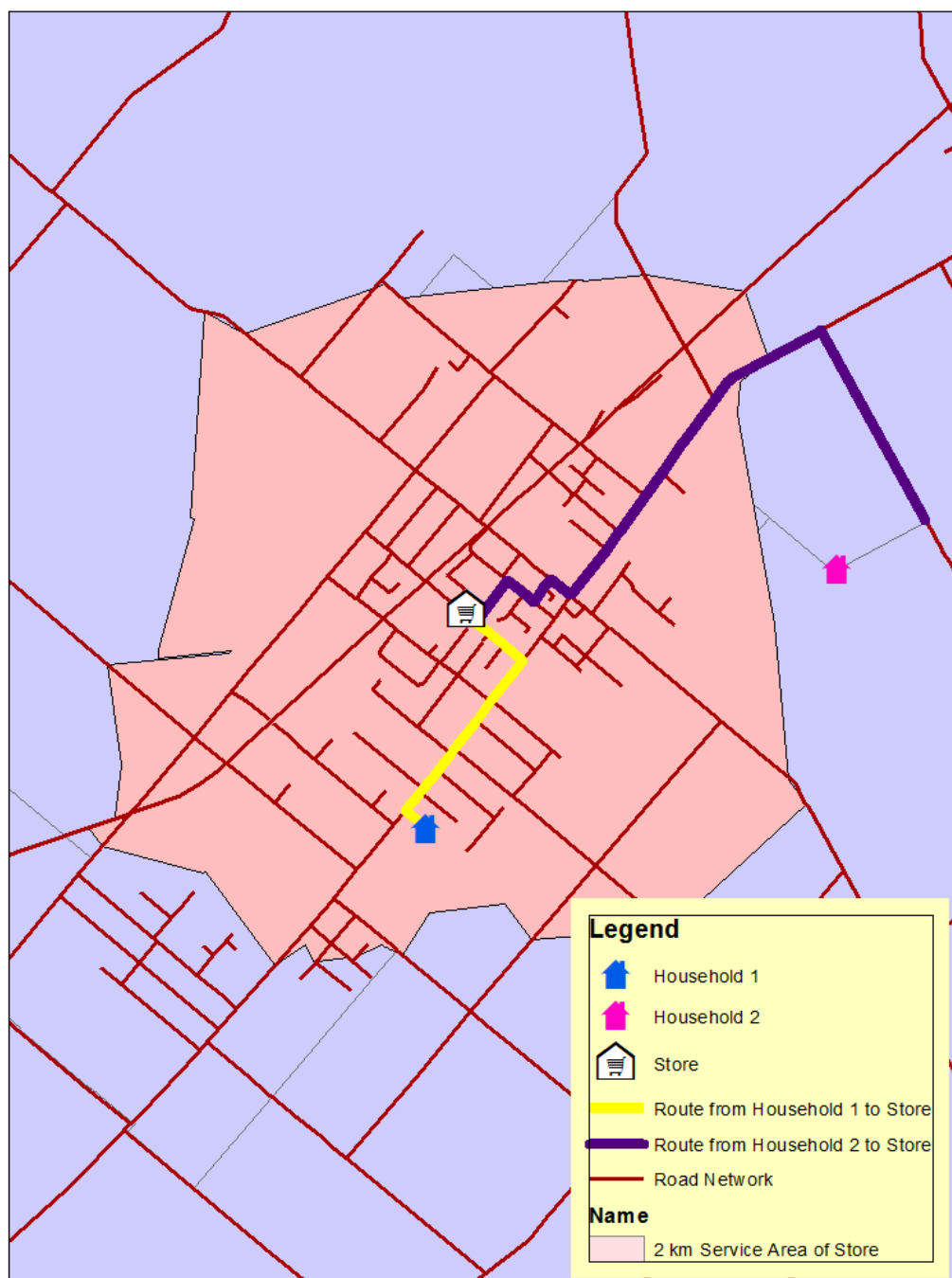


Figure 8.1.1 : 2 km service area of a store and walking access for households

## 8.2 Data Sources and Methodology

As with the creation of NZIFN model, the available geospatial data used in this study also required pre-processing and data sanitising steps. These processes are performed to the data sets before being applied to evaluate the AMA to the stores by potential customers. These steps are summarised in Table 8.2.1.

**Table 8.2.1: Summary of data sources and processing requirements**

Description	Source	File Type	Processing Requirement
New Zealand Meshblocks (2006)	Statistics New Zealand (Statistics New Zealand, 2006)	Geospatial dataset (Vector polygon)	Include information about census of population and dwellings and classify according to TAs. TAs will also be classified according to their population densities.
New Zealand 2006 Census of Population and Dwellings	Statistics New Zealand (Statistics New Zealand, 2006)	CSV files classified according to regions	Create a new CSV file of the Census data classified according to their TAs.
New Zealand road network (road centrelines)	Land Information New Zealand (Land Information New Zealand, 2011b)	Geospatial dataset (Vector line string)	Classify and split according to regions and then to TAs. For the service area analysis, consider only roads with pedestrian and biking access.
New Zealand supermarket locations	Zenbu (Zenbu, 2008)	Geospatial dataset (Vector point)	Split according to their TA location.
New Zealand Farmers' market locations	Farmers' market website (Farmers' Market NZ Inc, 2012)	Address or location written on the website	Needs to be encoded into a geospatial dataset and split according to their TA location.

The geo-spatial scale of analysis used in this model is the Territorial authority units or TAs which denotes the second tier classification of local government below regional councils as discussed in Chapter 3.1. Territorial authorities are the cities and towns of New Zealand and using this geographic level of assessment allows our model to make a meaningful analysis as the TA is an intermediate measure between regional and the mesh block scales.

A metric for classifying TAs according to population density is prescribed in Table 8.2.2. The 500 people/km<sup>2</sup> threshold is chosen since most New Zealand TAs have population densities less than 1000 people/km<sup>2</sup> except for Auckland and Waikato city. Christchurch, the biggest city in the South island has a population density of 753 people/km<sup>2</sup> (Statistics New Zealand, 2006).

**Table 8.2.2: Classification of New Zealand Territorial Authorities**

Classification	Density (people/km <sup>2</sup> )	Number of TAs in New Zealand
High Density	> 500	8
Medium Density	50-500	10
Low Density	< 500	65

### Model details

1) Run service area analysis for all supermarkets in a given territorial authority and looping throughout all the regions. The following parameters are used: 2-km impedance factor, from road network locations to the stores, service areas may overlap.

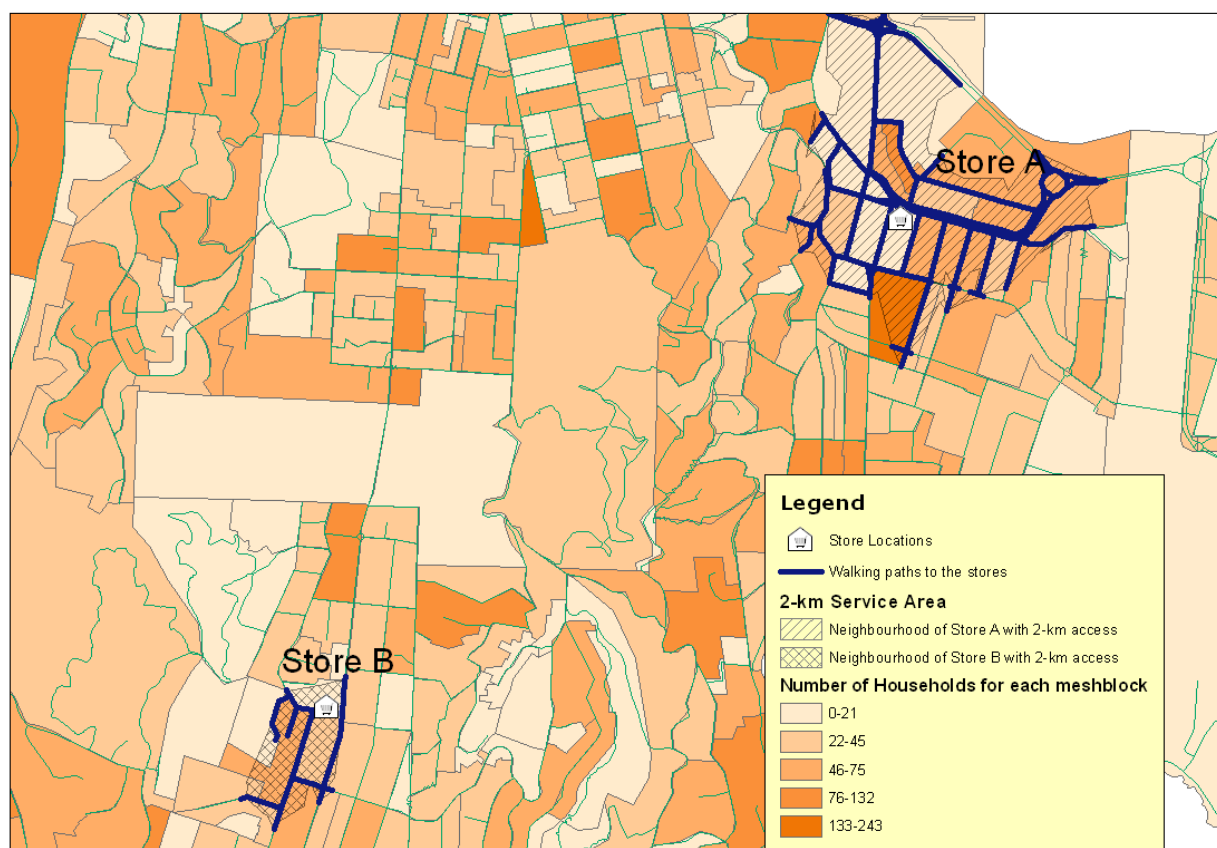
Do the same for all Farmers' markets.

- 2) Extract the polygons from all the service area layers obtained for each store.
- 3) Intersect each polygon with the original TA census data containing the demographic information of population and household counts.
- 4) Add new fields to the intersected polygon datasets. Compute the percentage of the area intersected with the polygon to the original area to obtain an estimate of the population and households in the resulting service area polygons.
- 5) Extract statistics for the total number of population and households in each 2-km service area of the store.

A Python script is written to automatise the whole process as this will take a significant amount of time to manually perform this for all supermarkets and Farmers' markets in New Zealand.

There are many factors that determine the AMA for stores such as the network data and distribution of population or household in the given area of study, which in this case is in meshblocks. Figure 8.2.1 illustrates a comparison of service areas of 2 stores located in the same TA but with different levels of access for potential customers. For Store A, 1863 people and 793 households have 2-km walking or biking access to the facility. In contrast for Store B, only 380 people and 136 households have 2-km walking or biking access to the facility. The reason for this stark contrast is the available walking/biking paths infrastructures as well as the density of the meshblocks in the neighbourhood of the stores.





**Figure 8.2.1 : Comparison of the service areas of 2 stores**

### 8.3 Results and Discussion

The AMA evaluation tool for the stores described in this chapter is determined by the available walking/biking paths infrastructures as well as the density of the meshblocks in the neighbourhood of the stores. The model is exhaustively tested for all supermarkets and Farmers' markets in New Zealand categorized by the density of its TAs. In total there are 666 supermarkets and 32 Farmers' markets that the Python script evaluated for their respective AMAs. The AMAs in this study were gauged by the average number of population and household access to the stores. The results of the model run are given on Table 8.3.1.

**Table 8.3.1 : Summary of population and households with AMA to the stores**

		Supermarkets	Farmers Markets
High Density TAs	Number of Stores	182	11
	Average number of people with 2- km access	967	941
	Average number of households with 2-km access	382	424
Medium Density TAs	Number of Stores	110	2
	Average number of people with 2- km access	1124	908
	Average number of households with 2-km access	402	361
Low Density TAs	Number of Stores	374	19
	Average number of people with 2- km access	584	742
	Average number of households with 2-km access	234	296
Whole New Zealand	Number of Stores	666	32
	Average number of people with 2- km access	778	826
	Average number of households with 2-km access	302	346

For high density TAs, although slightly more people have AMA to the supermarkets, more households have AMA to the Farmers' markets, accentuating subtle distinctions in the demographic distribution of population in different locations. Locations with lower

population count relative to households may suggest smaller sized families or single-person families.

The medium density TAs is in favour of the supermarkets however since only 2 Farmers' markets are located in this classification, the results may not be as accurate. For lower density TAs, Farmers' markets are usually located in the city centre or the town plaza, which is highly accessible for residents, hence could explain the relatively higher averages compared to the supermarkets.

As an extension of this study, it is possible to determine the percentage of New Zealand population and households that have AMA to stores, which could either be supermarkets or Farmers' markets. The values are given on Table 8.3.2 which shows that only 13% of New Zealanders have AMA to food stores. Using the metric prescribed in this chapter, this implies that most people would need to drive or take public transportation to access the stores.

This type of analysis has significant consequences on risks of food security related to fuel price increase. In this case, the adaptation potential measured by AMA suggests that people need to live in places with better access to services such as food stores. As majority of the population (approximately 87%) are located more than 2-km away from the nearest store, they are at substantial risk when driving or public transport becomes more expensive.

**Table 8.3.2 : New Zealand Population with AMA to Stores**

	Population	Households
Total number with AMA to Supermarkets	518,242	201,428

Total Number with AMA to Farmers' Markets	26,969	11,008
Total Number with AMA	544,511	212,436
New Zealand Total	4,082,091	1,564,200
<b>Percentage with AMA</b>	<b>13.3%</b>	<b>13.6%</b>

## 8.4 Conclusion

Including customer access in freight transport analysis allowed a comprehensive approach in the investigating freight and supply chains in a constrained system. Determining the Active Mode Access (AMA) of customers to facilities such as supermarkets and Farmers' markets captured the understated interplay between freight and personal transport and how freight supply chains influences the latter's travel patterns.

This added dimension of the study yielded interesting results to counter the arguments that Farmers' market customers mostly drive to the stores and consume fuel. At present, the customers of the Farmers' markets may be driving to the stores to procure their goods, but they may *have the option of walking* to the stores. In particular, we have shown that people and households have the same level AMA to both supermarkets and Farmers' markets, regardless of the population density of the towns or cities.

In particular for smaller towns, Farmers' markets are in good strategic locations, usually in the centre of the plazas, and more customers can access the stores via active mode compared to the supermarkets. However, this may be due to the fact that there is only one

Farmers' market in that small town, while several supermarkets are present, thus averaging their values result in the lower AMA score. Of course, these analyses do not assume that customers would actually want or willing to walk to the stores, but they have the option to do so, regardless of the motivation.

However, it was also shown that only 13% of New Zealanders have AMA to stores from their place of residence. This implies higher risk and vulnerabilities to fuel price increases as non-active mode access to stores would be more expensive.

## Chapter 9: Conclusions and Recommendations

The research presented is a novel paradigm that deviates from the norm or conventional existing mechanisms and methodologies in analysing freight transport in the supply chain context. The framework examined a constrained setting where transport costs also accounts for energy and environmental impacts instead of the usual logistics optimization techniques for reducing price and time of deliveries. The links of the commodity chain were examined using only geographical attributes and related features and were then evaluated for potential changes in the whole system. When necessary, geospatial attributes are used as proxies to economic parameters in modelling the supply chain dynamics. The potential changes in the system may be viewed as mitigation strategies and is a foundation of risk assessment.

### 9.1 General Conclusions

The resulting model called 'Geographic Adaptive Potential' or GAP is a framework for both macro and micro-level assessment of the potential scenarios for changes in the links of the supply chain. GAP of freight transport and production is a measure of the system's resiliency and the capacity to continue its function with diminished energy supply and reduced emissions. A system with GAP is able to deliver the same goods in the supply chain using less energy and producing lower emissions.

The GAP model has four components, each denoting a specific link in the supply chain. The components could be interdependent or mutually exclusive scenarios. Moreover, they may

co-exist simultaneously resulting in a system with a higher measure of GAP, which is defined as a system more resilient to changes brought by constraints.

The adaptive potential of the freight transport and production system was evaluated by the model components of GAP. The configuration of GAP allowed the system to be assessed for its adaptive potential using the following steps:

- a) Calculate the potential benefits of shifting to less-energy and emissions intensive modes for long-distance freight haulage.
- b) Determine the logistical and operational strategies employed in the last leg of the chain that relates to freight energy usage.
- c) Measure the efficiency and potential improvements of the local food production system in terms of freight energy intensity.
- d) Evaluate active mode access of end-customers in procuring the goods.

The results of the analysis of the 4 components of GAP showed achievable but limited adaptability potential of the freight and transport system. For the long-haul transport, there are up to 10% savings of shifting to less energy and emissions modes like rail and coastal shipping. However due to network infrastructure, product-type and mode compatibility constraints and other practicality concerns such as the geographic terrain of New Zealand, the benefits or savings are also limited.

Logistical decisions in the last-leg of the supply chain involved both physical and operational characteristics of stores. These factors influence the truck trips needed for replenishing the goods at the stores as well as the necessary freight energy. Supermarkets use more freight energy than smaller stores such as Farmers' markets and convenience

stores. However in terms of energy intensity, supermarkets are much more efficient owing to the large volume of goods delivered to them and through the utilisation of better logistical strategies such as freight consolidation and the use of distribution centres.

Using a study on product traceability and freight transport energy audit, it was also shown that localised production and distribution system such as Farmers' markets is actually more energy-intensive than the conventional food distribution system such as supermarkets. This result is contrary to the hypothesis that Farmers' markets consume less energy because of the shorter distances travelled from farms to the markets. The hypothetical simulation of vehicle routing for freight consolidation for the Farmers' market is an attempt to increase its food distribution efficiency. However, the calculations showed that in spite of freight consolidation scenario, the Farmers' market remain to be more energy-intensive than the supermarket system.

On the other hand, both Farmers' markets and supermarkets have the same level of active mode access for their potential customers. This result implies that the customers with AMA to the stores could actually walk to the stores and do not need to consume any fuel. However, in general, the model showed that only 13% of New Zealanders have this active mode access which puts the majority of the population at risk for fuel price increase. The AMA analysis provided an indicator for re-engineering people's lifestyles in such a way that they live in places with better access to services such as food stores.

Due to the limits of potential adaptability, the ultimate conclusion is that in the post-peak oil and low-carbon era, reduction in fuel supply and allowed emissions would also be equivalent to a decrease in freight movements along the supply chain. This result is



consistent with the motivational statement in this research which is demand reduction and an imminent paradigm shift in the transport and logistics sector.

## **9.2 For Future Work**

One of the main motivations for the case studies in this dissertation is the lack of available data for freight energy usage in New Zealand. Even though there are several useful government reports and databases which served as reference materials for this thesis, they do not show the actual interplay between freight movements and energy usage and emissions. Moreover, the freight data given are mostly in aggregated format which obscured the micro-level dynamics of the system.

For this reason, we highly recommend data collection efforts similar to the 'Truck trip generation' and 'Localised production' studies presented in this research which served as frameworks for conducting freight energy audit.

Likewise, the NZIFN study which is patterned after a similar study called GIFT in the United States has encountered major obstacles in obtaining data for pollutants such as particulate matter [ $PM_{10}$ ], [ $PM_{2.5}$ ], nitrogen oxides [ $NO_x$ ], and sulphur oxides [ $SO_x$ ]. The interviews conducted with EECA as well as the rail and shipping companies revealed that the organisations do not have any estimate or measure for these pollutants and hence were excluded as parameters in the NZIFN model. We propose that these pollutants are accounted for in the freight transport sector as they are known to have detrimental effects on human health, vegetation and climate.

Another improvement for the NZIFN model is to simulate the oil price increase trends and cap on emissions and reflect these values on the operations costs. This entails the determination of a saturation point for which modal shift is imminent thus necessitating immediate improvements in the intermodal facilities and network infrastructure. Through this, it is possible to evaluate the risk exposure of the current scheme of distribution with higher percentage of commodities still being shipped by trucks and is incapable of modal shift.

For the truck trip generation study, the introduced parameter product variation score was shown to have high correlation with the number of truck trips generated by the store. It has deep connections with the issue of product essentiality. This aspect raises a fundamental question of whether the high product variation score is imperative in sustaining the commodity chain or is it a matter of consumer lifestyle choices. As we have repeatedly mentioned, consumer behaviour is eliminated from our methodology, hence a possible extension of research is to derive another impartial measure addressing the concept of essentiality. Through this gauge, we seek to answer fundamental questions such as *“Do we really need 20 different brands or choices for eggs?”* and *“Are these essential products or sheer consequence of our lifestyle choices?”*

In the case study, limited number of data set failed to produce a statistically relevant conclusion but it established the main framework in obtaining a trip generation model for different type of stores. Moreover, we obtained a method for the calculation of freight energy consumption and fuel intensity of the distribution patterns of the stores. The input parameters to these calculations may be improved in succeeding studies. Likewise, trip chaining which is a significant result of complex tactical and operational logistics of both

store chains and freight distributors was not considered in the computation of the freight energy usage of the trucks. The data on deliveries to other stores were initially planned to be collected but due to the rushed nature of the driver's job and limited manpower of our survey team, it became impossible to determine actual trip chaining.

The conventional supermarket system is energy-efficient as it exploits economies of scale and geographic competitive advantages. However, Farmers' markets have the potential to reduce its freight fuel consumption through higher level logistical strategies and coordination between the Farmers or vendors. One future area of research would be to fabricate a system that incorporates both strengths of the system, probably in a collaborative effort between the two types of markets, that is a supermarket system utilising shorter network distance from point of production to consumption, reduced storage time, removing the processing and packaging steps, and sourcing produced from local or regional farmers.

As an extension of the AMA analysis, we can determine the balance or trade-offs of having one centralised store in a suburb for which only a few percentage of residents have AMA to the store, compared to an urban environment where smaller stores are scattered across neighbourhoods. A centralised store would immediately be able to apply freight consolidation and necessitate fewer truck trips, while the latter needs trip chaining, vehicle routing and scheduling and may result in more truck trips. The goal is to determine the trade-offs in total fuel usage, of both freight and personal transport in each setting.



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## APPENDIX A: Classical Transportation Models

### 1. The Gravity Model

Define  $T_{ij}^k$  as the tonnes of commodity/product  $k$  moved from  $i$  to  $j$ .

Then,

$$T_{ij}^k = A_i^k B_j^k O_i^k D_j^k \exp(-\beta^k C_{ij}^k). \quad (1)$$

where

$A_i^k, B_j^k$  are balancing factors in the usual sense of the gravity model

$O_i^k$  is the supply for product  $k$  at zone  $i$ , also called as the production at zone  $i$

$D_j^k$  is the demand for product  $k$  at zone  $j$ , also called as the attraction at zone  $j$

$\beta^k$  are calibration parameters, one per product  $k$ , and

$C_{ij}^k$  are generalized transport costs/ travel impedance per tonne of product  $k$  between zones  $i$  and  $j$ .

The usual situation is that trip productions and attractions for each zone are known (or have been estimated). Hence, we have the constraints:

$$O_i^k = \sum_j T_{ij}^k \quad (2)$$

and

$$D_j^k = \sum_i T_{ij}^k \quad (3)$$

Solving these non linear equations yield the following:

$$A_i^k = \left[ \sum_j B_j^k D_j^k \exp(-\beta^k C_{ij}^k) \right]^{-1}$$

and

$$B_j^k = \left[ \sum_i A_i^k O_i^k \exp(-\beta^k C_{ij}^k) \right]^{-1}$$

These balancing factors are interdependent hence calculation of one set requires the values of the other set. To solve for the  $A_i$ 's and the  $B_j$ 's, use an iterative process analogous to Furness's method for growth factor model which is described in (Ortuzar and Willumsen, 2001). The algorithm is as follows:

- i. Set all  $B_j = 1.0$ , and then solve for  $A_i$ , (ie, find the correction factors  $A_i$  satisfying the trip generation constraints;
- ii. With the latest  $A_i$ , solve for  $B_j$ , (ie, satisfy the trip attraction constraints;
- iii. Keeping the  $B_j$ 's fixed, solve for  $A_i$  and repeat steps (2) and (3) until the changes are sufficiently small.

This method produces solutions within 3 to 5% of the target values in a few iterations.

There is not much point in enforcing the constraints to a level greater than the accuracy of the estimated trip end totals. The most important condition required for the convergence of this method is that the balancing factors produce target values  $T_i$  and  $T_j$  such that:

$$\sum_i A_i \sum_j f(c_{ij}) = \sum_j B_j \sum_i f(c_{ij}) = T_{ij}$$

The generalized function  $c_{ij}$  includes several aspects which is dependent on the mode of transport used and the commodity type being transported:

- pocket charge for using service from  $i$  to  $j$
- travel times between  $i$  and  $j$
- variability of time travel
- waiting time or delay
- probability of loss or damage, such as penalties incurred

The calibration parameter  $\beta$  actually determines the relative contribution of transport cost to the final cost of a commodity (knowing the selling price in the market). If  $\lim \beta = 0$ , then this corresponds to commodities where transport cost play no role, such as electronics, chocolates. On the other hand if  $\lim \beta \rightarrow \infty$  then this corresponds to products where transport costs are dominant, such as bricks, cement.

## Model Calibration

In adjusting the model parameter  $\beta$ , it is important to consider an agreement between the *observed* (based year) trip distribution and the *predicted* (base year) distribution. From a transportation survey, one can obtain a frequency distribution of trip length (for the base year). For all origin-destination pairs  $i, j$ , distribute trips between them based on a distance function (to represent utility). This yields an average trip length which must match an observed known total.

From the trip length distribution, one can obtain a 'seed' matrix in which the starting matrix of assigned network flows is matched with the observed network flows. To find the final road matrix, do adjustments via iterations on the freight matrix such that it converges to the observed data. Here, we can measure the goodness of fit by the coefficient of determination  $R^2$  given by:

$$R^2 = \frac{\sum (\hat{Y}_i - \bar{Y})^2}{\sum (Y_i - \bar{Y})^2}$$

where

$Y_i$  is observed value of the dependent variable for sample  $i$

$\hat{Y}_i$  is the fitted (estimated) value of the dependent variable for sample  $i$

$\bar{Y}$  is the sample mean of  $Y_i$  values

## 2. Shortest Path Algorithm: Formulation with Transfers

Find shortest path from origin  $o \in O$  to all destinations  $d \in D$ . The shortest path is retraced by means of pointers to the preceding link:  $b_d$  is the access link to destination  $d$ ,  $b_a$  is the predecessor of link  $a$ ; the length of the shortest paths are given by variables  $u_d$  and  $u_a$ , where  $u_a$  is the length of the shortest path from origin  $o$  to link  $a$  inclusive  $c_a$ ;  $\bar{A}$  represents the set of links which were examined (labelled) but do not yet have permanent labels. Let  $m(p)$  be the set of modes for product  $p$ .

Step 0: Initialisation

Lengths:

$$u_d = \infty, d \in D, u_o = 0; u_a = \infty, a \in A$$

Predecessors:

$$b_d = -1, d \in D, b_o = 0; b_a = 0, a \in A$$

Links to label:

$$\bar{A} = \emptyset$$

Dummy arc:

$$\bar{a} = (\bar{i}, \bar{j}, \bar{m}) \text{ with } \bar{i} = 0, \bar{j} = d, \bar{m} = m(p); u_{\bar{a}} = 0$$

Go to Step 4.

Step 1. Choice of arc to label

If  $\bar{A} = \emptyset$  then STOP.

Choose  $\bar{a} = (\bar{i}, \bar{j}, \bar{m})$  of  $A$  such that  $u_{\bar{a}} \leq u_a$  for all  $a \in \bar{A}$

Arc  $\bar{a}$  receives a permanent label:  $\bar{A} = \bar{A} - [\bar{a}]$ .

If  $\bar{j}$  is a transfer node, go to Step 3; if  $\bar{j}$  is a regular node, go to Step 4; otherwise continue.

Step 2. Test of “head” node  $\bar{j}$  (for destination node)

If  $u_{\bar{a}} \leq u_{\bar{j}}$  then  $u_{\bar{a}} = u_{\bar{j}}$ ;  $b_{\bar{j}} = \bar{a}$ .

Return to Step 1.

Step 3. Scan of successors with transfers

For each  $a = (i, j, m)$  such that  $i = \bar{j}$  and  $m \in m(p)$

Do:

If there is a transfer  $t = (\bar{a}, a)$  do:

If  $u_{\bar{a}} + c_t + c_a < u_a$

Then  $u_a = u_{\bar{a}} + c_t + c_a$ ;  $b_a = \bar{a}$ ;  $\bar{A} = \bar{A} \cup [a]$

Otherwise, if  $m = \bar{m}$  do:

If  $u_{\bar{a}} + c_a < u_a$

Then  $u_a = u_{\bar{a}} + c_a$ ;  $b_a = \bar{a}$ ;  $\bar{A} = \bar{A} \cup [a]$

Return to Step 1.

Step 4. Scan of successors without transfers

For each  $a = (i, j, m)$  such that  $i = \bar{j}$  and  $m = \bar{m}$  do:

$$\text{If } u_{\bar{a}} + c_a < u_a$$

$$\text{Then } u_a = u_{\bar{a}} + c_a; b_a = \bar{a}; \bar{A} = \bar{A} \cup [a]$$

Return to Step 1.



### 3. Vehicle Routing Problem: Formulation with Transfers

The basic formulation of general VRP is defined as follows:

Let  $G = (N, L)$  be a graph where  $N = [x_1, \dots, x_n]$  is a set of nodes representing the customers with the depot located at node  $x_1$ , and  $L$  is the set of links. For every link  $l_{ij}(i, j)$  with  $i \neq j$ , the cost of transport from  $i$  to  $j$  denoted by  $c_{ij} \geq 0$ . Assume  $M = [v_1, \dots, v_m]$  is a set of vehicles originating at the depot with capacities  $Q = [q_1, \dots, q_m]$ . The VRP is finding the least-cost vehicle routes design such that:

- a) Each customer  $V \setminus x_1$  is visited exactly once by one vehicle;
- b) All vehicle routes start and end at the depot.

Let  $\varepsilon_{ij}$  ( $i \neq j$ ) be a binary variable equal to 1 if and only if the link  $l_{ij}(i, j)$  appears in the optimal solution. The goal is to minimise:

$$z = \sum_{i \neq j} c_{ij} \varepsilon_{ij}$$

Subject to:

$$\sum_{i=1}^N \sum_{k=1}^M \varepsilon_{ijk} = 1, j = 1, \dots, N$$

$$\sum_{i,j \in S} \varepsilon_{ij} \leq |S| - v(S) \quad (S \subset V \setminus x_1; |S| \geq 2)$$

Where

$v(S)$  is an appropriate lower bound on the number of vehicles required to visit all vertices in  $S$  in the optimal solution.

## Appendix B: Summary of the survey findings of the PricewaterCoopers report

Scoring legend:

EP = Estimated Probability (0-100%)

C = Consensus (interquartile range  $\leq 25$ ) | dissent (interquartile range  $> 25$ )

I = Impact (5-point-Likert scale)

D = Desirability (5-point-Likert scale)

R = Desirable

### Results On Supply-Chains

Area	Projections for year 2030 (theses)	EP	C	I	D
Energy/ Emissions	The oil price has risen to \$1000 per barrel because of peak oil production decades ago.	27%	10	4.6	1.7
	The global energy turnaround has now advanced to the point so that in some countries alternative energy accounts for up to 80% of the overall energy mix.	52%	38	3.8	4.0
	Using emissions trading toll systems, the carbon footprint of logistics processes in supply chains must be allocated to the actual causer and factored into the price of the product.	69%	20	4.1	3.9
Consumer Behaviour	Consumer behaviour has changed such that locally produced products	60%	20	3.9	3.5

	are strongly preferred				
Transport Modes	Larger means of transport have become prevalent to compensate for rising transportation costs.	60%	25	3.7	3.1
	The debate over modal shift is obsolete. The share of road transportation in the modal shift has further increased.	50%	20	3.7	2.4
Supply chain design	The minimisation of energy consumption is the paramount criterion in supply chain design, rather than cost efficiency and speed.	55%	28	3.7	3.7

### On Transport Infrastructures

Area	Projections for year 2030 (theses)	EP	C	I	D
Supply & Demand	There is no longer a shortage of transport infrastructures since sufficient investments have been made.	30%	20	4.1	4.2
	Transport infrastructure development strongly focuses on urban areas, while rural areas are neglected.	68%	20	3.7	2.9
	Infrastructure shortages have forced the division of megacities into decentralised, autonomous “sub-cities”.	50%	30	3.6	3.0

### Methodology of study:

Methodology is survey-based which is conducted in real-time and comprises of 2 rounds. Participants were asked to rate the theses’ probability of occurrences (0-100%), impact on Transport and Logistics sector if occurred (5-point-Likert scale), and desirability (5-point-Likert scale) as well as to provide reasons for all answers (optional). After conclusion of 2 rounds, a consensus portal was activated which gave an overview over the current divergences from the group.

### Participants:

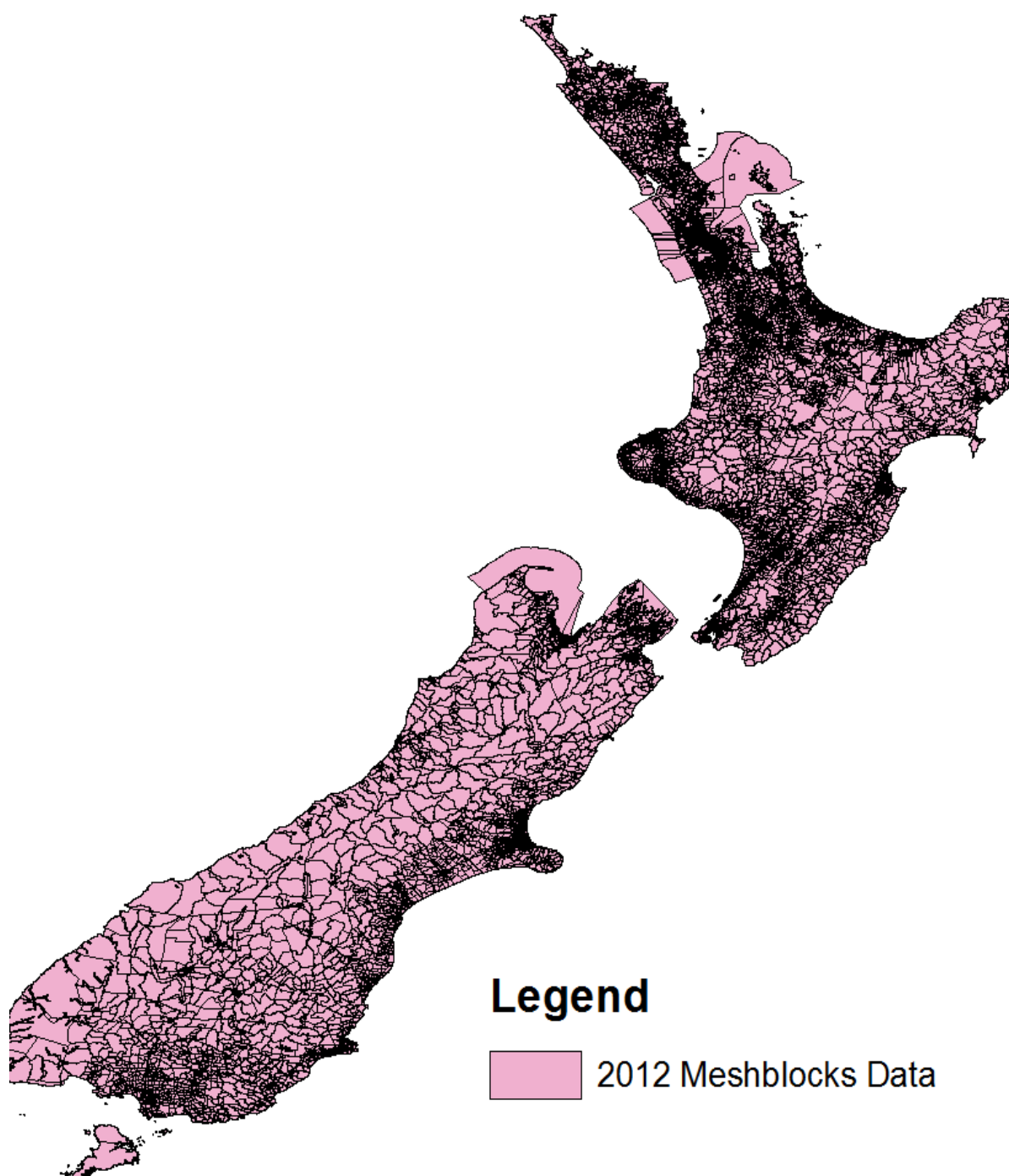
For the study on Supply Chains, there are 48 participants based in 20 different countries where 67% and 33% of respondents are from developed and emerging countries, respectively. They are segmented according to their field of expertise: academics (25%),

politics (10.4%), and industry practitioners (64.6%) of the following sub-categories – transportation, aviation, shipping and railways.

Meanwhile for the study on Transport Infrastructure, there are 104 participants based in 20 different countries where 62% and 38% of respondents are from developed and emerging countries, respectively. Segmentation of areas of expertise is as follows: 24% academics, 10% politicians, 28% transport infrastructure operators or developers, 27% transport infrastructure users and 11% associations.

## Appendix C: New Zealand Geospatial Data

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Figure C.3.1 : New Zealand meshblock units' dataset

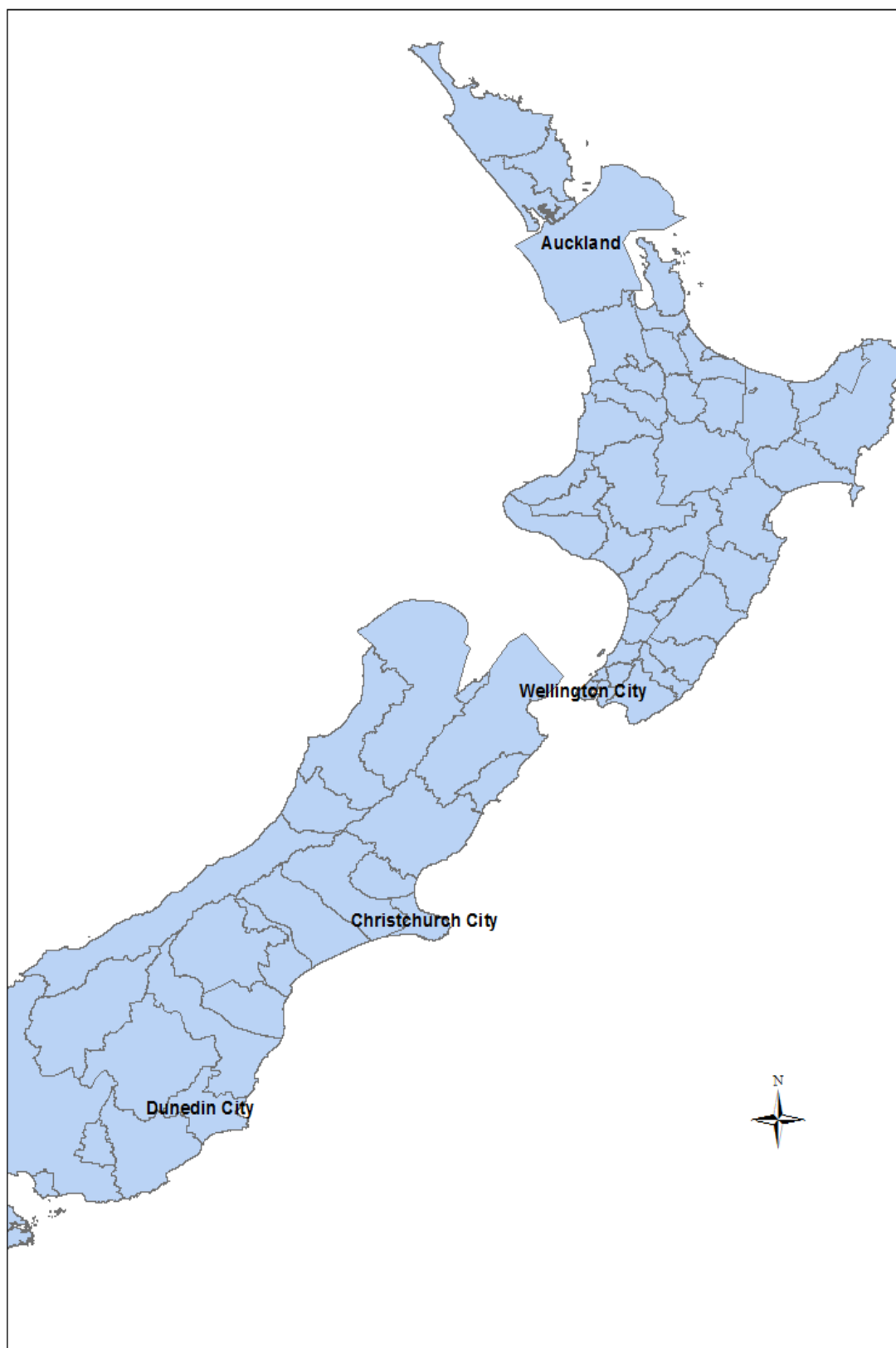
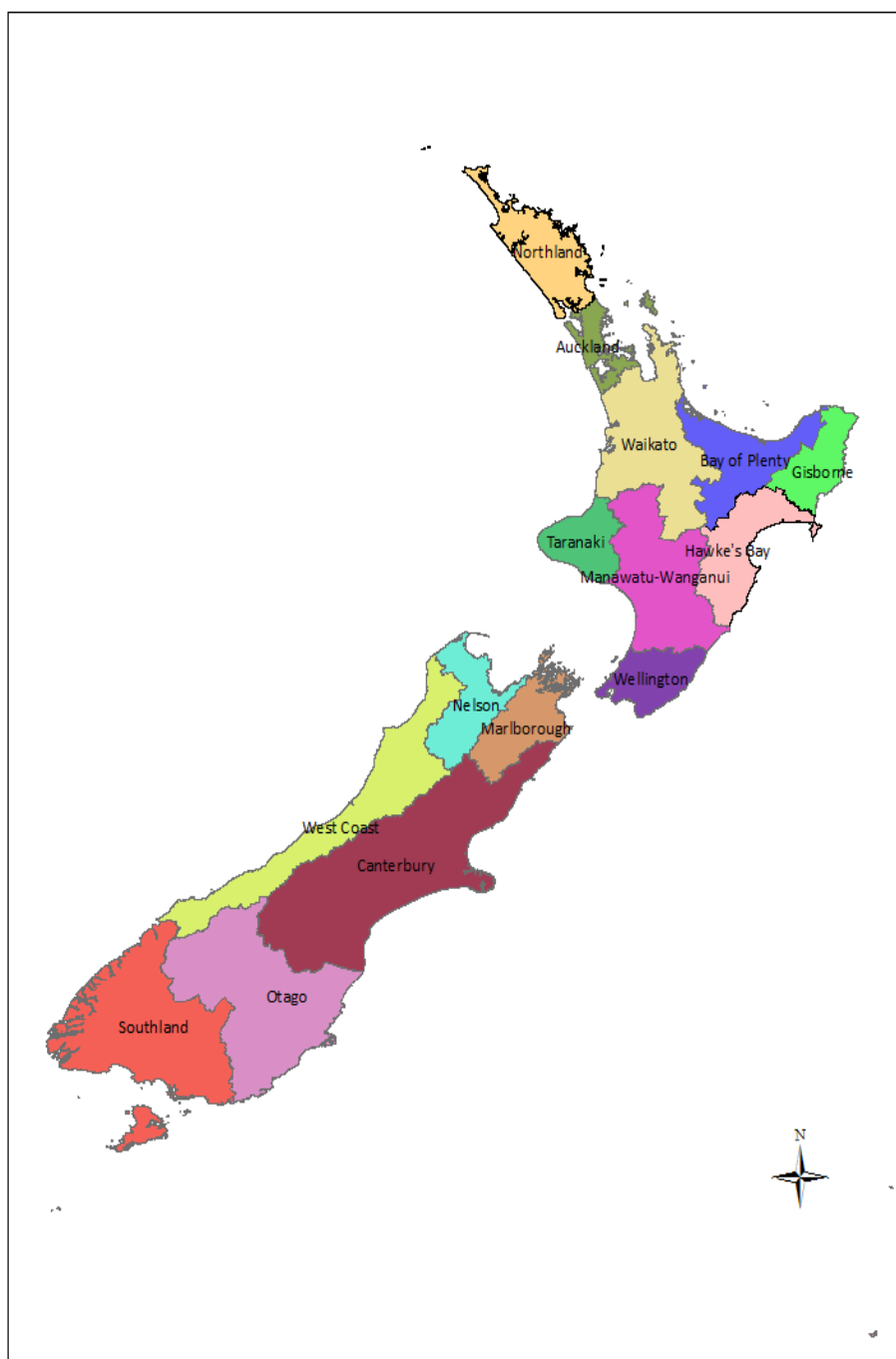


Figure 3C.3.2: New Zealand territorial authority units' dataset



**FigureC.3.3: New Zealand territorial 16 administrative regions**



## Appendix D: Survey Files

### 1. Rail and Ports Questionnaire

College of Engineering

Department of Mechanical Engineering  
Tel: +64 3 364 2687 loc 46503  
www.mech.canterbury.ac.nz  
janice.asuncion@pg.canterbury.ac.nz



01 May 2012

(Name)  
(Position)  
(Company)

Dear Mr. \_\_\_\_\_,

I am a PhD student in the Department of Mechanical Engineering, University of Canterbury and I am contacting you to get some data about fuel/energy use and emissions of moving freight by (company). My project is entitled "New Zealand Intermodal Freight Network and the Potential for Mode Shifting" and the data that we will obtain from this study will be used to investigate the different modes of freight transport in New Zealand and evaluate the tradeoffs in terms of operational costs, time-of-delivery, energy consumption and emissions. Through this, we would propose to investigate the benefits of shifting from trucking to less energy and emissions-intensive modes such as rail or shipping. We know that there are feasibility constraints in terms of existing infrastructure, technology and mode preference of companies, which is why we seek to understand the current state of operations of these modes of transport as well as the intermodal transfer facilities.

The following is the list of the specific data from (company) that we are after:

- Number of annual TEU's moved by (company) in major hubs such as Auckland, Wellington, New Plymouth, Christchurch and Picton.
- Total annual operation costs in the above-mentioned hubs.
- Main commodities/goods which are moved in the above-mentioned hubs.
- Total annual energy usage estimated by fuel consumption of the trains
- Estimated energy intensity of moving 1 TEU by rail
- Total annual emissions estimated by fuel consumption of the trains (CO<sub>2</sub>, PM<sub>10</sub>, SO<sub>x</sub>, N<sub>2</sub>O, CH<sub>4</sub> or whatever is available)
- Estimated greenhouse gas emissions intensity of moving 1 TEU by rail (CO<sub>2</sub>, PM<sub>10</sub>, SO<sub>x</sub>, N<sub>2</sub>O, CH<sub>4</sub> or whatever is available)
- Average transfer time from rail to trucks and vice versa
- Average transfer time from rail to shipping and vice versa

We understand that most of this information will not be directly available however we would appreciate any kind of data that we could use to calculate them.

To assure anonymity, your personal and business details will be encoded with an identification number and will be used in lieu of your company's name. In addition, any information about your participation will not be disclosed to other entities participating in the study. All published material regarding this study will be presented in a generalised format, and your company will not be identified in any way.

# College of Engineering

Department of Mechanical Engineering  
Tel: +64 3 364 2687 loc 45503  
www.mech.canterbury.ac.nz  
janice.asuncion@pg.canterbury.ac.nz



The project is being carried out as part of my PhD Dissertation and under the supervision of the following researchers of the Advanced Energy and Material Systems Laboratory and the University of Canterbury, listed below. They will be pleased to discuss any concerns you may have about participation in the project.

Thank you very much.

Yours,

Janice Asuncion  
PhD Candidate  
Department of Mechanical Engineering  
University of Canterbury

Cameron Matthews  
Research Assistant  
Department of Mechanical Engineering  
University of Canterbury

## Supervisory Team

Dr Susan Krumdieck  
Associate Professor  
Department of Mechanical Engineering  
University of Canterbury

Dr Rua Murray  
Senior Lecturer  
Department of Mathematics  
University of Canterbury

Dr Shannon Page  
Lecturer  
Department of Environmental Management  
Lincoln University

## Other Team Members

Stacy Rendall  
PhD Candidate  
Department of Mechanical Engineering  
University of Canterbury

## College of Engineering

Department of Mechanical Engineering  
 Tel: +64 3 364 2987 loc 46503  
 www.mech.canterbury.ac.nz  
 janice.asuncion@pg.canterbury.ac.nz



14 May 2012

(Name)  
 (Position),  
 (Company)

Dear Mr \_\_\_\_\_,

I am a PhD student in the Department of Mechanical Engineering, University of Canterbury and I am contacting you to get some data about fuel/energy use and emissions of (company). My project is entitled "New Zealand Intermodal Freight Network and the Potential for Mode Shifting" and the data that we will obtain from this study will be used to investigate the different modes of freight transport in New Zealand and evaluate the tradeoffs in terms of operational costs, time-of-delivery, energy consumption and emissions. Through this, we would propose to investigate the benefits of shifting from trucking to less energy and emissions-intensive modes such shipping or rail. We know that there are feasibility constraints in terms of existing infrastructure, technology and mode preference of companies, which is why we seek to understand the current state of operations of these modes of transport, as well as the intermodal transfer facilities.

The following is the list of the specific data that we are after:

- Annual number of TEU's moved by (company) in the ports of Auckland (Waitemata and Onehunga), Tauranga, New Plymouth, Lyttelton, and Nelson
- Total annual port operational costs
- Main commodities/goods handled by (company) in the above mentioned transfer hubs
- Total annual energy usage estimated by fuel consumption of the fleet
- Estimated ship energy use per TEU-km
- Total annual emissions, estimated by fuel consumption of the fleet (CO<sub>2</sub>, PM<sub>10</sub>, SO<sub>x</sub>, N<sub>2</sub>O, CH<sub>4</sub> or whatever is available)
- Estimated greenhouse gas emissions per TEU-km by ship (CO<sub>2</sub>, PM<sub>10</sub>, SO<sub>x</sub>, N<sub>2</sub>O, CH<sub>4</sub> or whatever is available)
- Average transfer time from ships to trucks and vice versa
- Average transfer time from ships to trains and vice versa
- Port cargo handling equipment energy usage per TEU
- Port heavy-duty-vehicle energy usage per TEU
- Cargo handling equipment emissions per TEU (CO<sub>2</sub>, PM<sub>10</sub>, SO<sub>x</sub>, N<sub>2</sub>O, CH<sub>4</sub> or whatever is available)
- Port locomotive operating emissions per TEU (CO<sub>2</sub>, PM<sub>10</sub>, SO<sub>x</sub>, N<sub>2</sub>O, CH<sub>4</sub> or whatever is available)
- Port-heavy-duty vehicle emissions per TEU (CO<sub>2</sub>, PM<sub>10</sub>, SO<sub>x</sub>, N<sub>2</sub>O, CH<sub>4</sub> or whatever is available)

We realise that some items listed above will not be directly available hence we would like to ask your permission to investigate the port equipments and transfer vehicles, and obtain information such as model number, engine size, age, condition, etc. Also, if possible, we would like to observe the port operations on 21 May 2012 (Monday). Kindly advise of the time when we can view loading and unloading of goods to/from the ship.

To assure anonymity, your personal and business details will be encoded with an identification number and will be used in lieu of your company's name. In addition, any information about your participation will not be disclosed to

### College of Engineering

Department of Mechanical Engineering  
Tel: +64 3 364 2687 loc 46503  
www.mech.canterbury.ac.nz  
janice.asuncion@pg.canterbury.ac.nz



The project is being carried out as part of my PhD Dissertation and under the supervision of the following researchers of the Advanced Energy and Material Systems Laboratory and the University of Canterbury, listed below. They will be pleased to discuss any concerns you may have about participation in the project.

Thank you very much.

Yours,

Janice Asuncion  
PhD Candidate  
Department of Mechanical Engineering  
University of Canterbury

Cameron Matthews  
Research Assistant  
Department of Mechanical Engineering  
University of Canterbury

### Supervisory Team

Dr Susan Krumdieck  
Associate Professor  
Department of Mechanical Engineering  
University of Canterbury

Dr Rua Murray  
Senior Lecturer  
Department of Mathematics  
University of Canterbury

Dr Shannon Page  
Lecturer  
Department of Environmental Management  
Lincoln University

### Other Team Members

Stacy Rendall  
PhD Candidate  
Department of Mechanical Engineering  
University of Canterbury

## 2. Survey on Supermarkets and Farmers' Markets

### College of Engineering

Department of Mechanical Engineering  
Tel: +64 3 364 2687 loc 46503  
www.mech.canterbury.ac.nz  
janice.asuncion@pg.canterbury.ac.nz



28 April 2011

The Manager

Dear Sir/Madam,

I am a PhD student in the Department of Mechanical Engineering, University of Canterbury. My project is entitled "Analysis of the Truck Trip Generation Characteristics of Supermarkets and Convenience Stores." The aim of this research is to understand the movement of goods in the Canterbury region by looking at truck flows into these retail chains and assess the fuel intensity and risk exposure of these stores to rising petrol prices.

As a participant for this research, I would like to request the following:

- A short interview about the characteristics of the store, operations, deliveries and your personal perception of the store's vulnerabilities to rising fuel prices. This will take around 15-20 minutes.
- Allow us to take measurements on the size of the trading area, storage and parking spaces using a portable laser measurer. However, if you already know these values then you may simply provide this information during the interview.
- Give permission to me and/or members of the research group to observe and manually count the delivery trucks outside the store premises. We would like to do this for 2-3 days and the dates that we will select to conduct our data gathering will depend on your answers on the interview.

As an incentive for your participation, we will provide you with a detailed report of your truck trip rates as compared to the average amongst all participants (without revealing specific information about other participants). Moreover, we have already conducted a personal transport accessibility study on urban areas of New Zealand and this analysis will be useful in determining how potential customers will be affected by the increase of the price of petrol. You may freely use this report for your own purposes.

The data collected is strictly confidential and will be used only for research purposes and will ONLY be accessible by the research group members below. Furthermore all information related to this study will be stored in a password protected hard-disk.

To assure anonymity, your personal and business details are encoded with a randomly-generated identification number and will be used in lieu of your name. In addition, any information about your participation is not disclosed to other participants and all published material on this study will be in aggregated and generalised format and the company will not be implicated in any way.

As a participant, you may withdraw anytime from this project and the information you have provided will be excluded from the results of the project. Moreover, you may also request the immediate deletion of any initial data that you have provided.

The project is being carried out as part of my PhD dissertation and it is under the supervision of the following researchers listed below. They will be pleased to discuss any concerns you may have about participation in the project.

# College of Engineering

Department of Mechanical Engineering  
Tel: +64 3 364 2687 loc 46503  
www.mech.canterbury.ac.nz  
janice.asuncion@pg.canterbury.ac.nz



Thank you very much.

Yours,

Janice Asuncion  
PhD Candidate  
Department of Mechanical Engineering  
University of Canterbury

## Supervisory Team

Dr Susan Krumdieck  
Associate Professor  
Department of Mechanical Engineering  
University of Canterbury

Dr Elijah Van Houten  
Senior Lecturer  
Department of Mechanical Engineering  
University of Canterbury

Dr Rua Murray  
Senior Lecturer  
Department of Mathematics  
University of Canterbury

Dr Shannon Page  
Lecturer  
Department of Environmental Management  
Lincoln University

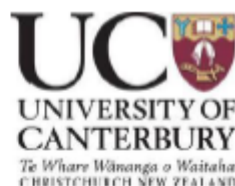
## Other Team Members

Thomas Sanchez  
Visiting Researcher  
Department of Mechanical Engineering  
University of Canterbury

Stacy Rendall  
PhD Candidate  
Department of Mechanical Engineering  
University of Canterbury

College of Engineering

Department of Mechanical Engineering  
Tel: +64 3 364 2687 loc 45503  
www.mech.canterbury.ac.nz  
janice.asuncion@pg.canterbury.ac.nz



18 April 2011

#### CONSENT FORM FOR PARTICIPANTS

##### Analysis of Truck Trip Generation Characteristics of Supermarkets and Convenience Stores

I hereby acknowledge that I have read and understood the description of the above-named project. On this basis I agree to let the store participate in the study thereby granting permission to Janice Asuncion and/or Thomas Sanchez to observe and manually count the number of trucks outside the store premises.

I understand that all reference to me or the store will use a randomly-generated identification code instead of my name or the store's name.

I consent any publication of results related to this project with the understanding that anonymity will be preserved, and that the data will remain confidential and presented in an aggregated and generalized format that will not implicate the store or company in any way.

I also understand that I may at any time withdraw this store from the project, including withdrawal of any information I have provided.

In signing this form, I attest to my authority to provide the consent required for this project.

NAME (please print):

Signature:

Date:

Participant ID: \_\_\_\_\_

## Survey Questionnaire

Participant ID: \_\_\_\_\_ 2011

For official use only

## A. General Store Information

## a. Size

Gross Floor Space (m <sup>2</sup> )	Storage Space (m <sup>2</sup> )	Number of Docks	Parking Space (m <sup>2</sup> )	Truck Parking Space (m <sup>2</sup> )

## b. Hours of business and operation

Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Public Holidays

## c. Store employees

Number of full-time employees: \_\_\_\_\_

Number of part-time employees: \_\_\_\_\_

Employee shifts:	Number of employees
Daytime shift	
Night shift	
Others: _____	

## B. Deliveries

## a. Where deliveries are accepted? (Check all that applies)

☐ Front door      ☐ Loading dock      ☐ Off street

## b. Delivery time window(s): \_\_\_\_\_

## c. Constraints on accepting deliveries: (e.g. council bylaws, human resource, etc.) \_\_\_\_\_

## d. How many deliveries do you expect on a typical day? \_\_\_\_\_

## e. On a typical week, which day has the maximum number of deliveries: \_\_\_\_\_

## f. On a typical week, which day has the minimum number of deliveries: \_\_\_\_\_

## g. Differences between weekdays and weekends (if any): \_\_\_\_\_

## h. Are there seasonal variations of deliveries? (Briefly explain any increase or decrease) \_\_\_\_\_

## i. How many trucks service the facility for the purpose of trash and recycling? (Specify schedule of collection) \_\_\_\_\_

## j. What are the effects of the February earthquake on your delivery operations? (if any) \_\_\_\_\_

## C. Depot Information

a. Does the store have a depot/warehouse? ☐ Yes ☐ No

## b. If yes:

Depot Location: \_\_\_\_\_

Which goods/brands come from your depot? \_\_\_\_\_

## D. Personal Assessment (Rate high, medium or low)

## a. How do you rate the vulnerabilities of your deliveries to rising petrol prices? \_\_\_\_\_

## b. How do you rate the vulnerabilities on losing potential customers as a consequence of rising petrol prices? \_\_\_\_\_

## c. How do you rate the overall "environmental-friendliness" of the store? \_\_\_\_\_



2011

Manual Truck Counts  
Date of Observation: \_\_\_\_\_

Participant ID: \_\_\_\_\_  
Day: \_\_\_\_\_

For official use only

No.	Arrival Time	Departure Time	Truck Type <sup>1</sup>	Commodity Type <sup>2</sup>	Origin of loading <sup>3</sup>	Other stops in the route <sup>4</sup>	Load or Unload?	Plate Number	Other Notes
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									
15									
16									
17									
18									
19									
20									
21									
22									
23									
24									
25									
Total number of items: _____									

<sup>1</sup>Truck Type – refer to FHWA 13-Bin Vehicle Classification  
<sup>2</sup>Commodity type – the general type of goods, if known  
<sup>3</sup>Origin of loading – factory, warehouse, other store, if known  
<sup>4</sup>Other deliveries – yes, or no, specify if known

Name of Observer: \_\_\_\_\_

### 3. Survey on Farmers' Markets (Localised Production Study)

College of Engineering

Department of Mechanical Engineering  
Tel: +64 3 364 2987 loc 46503  
www.mech.canterbury.ac.nz  
janice.asuncion@pg.canterbury.ac.nz



29 June 2012

(Name)

(Position)

(Farmers' Market Location)

Dear Mr. \_\_\_\_\_,

I am a PhD student in the Department of Mechanical Engineering, University of Canterbury. I am conducting a research on the energy intensity of the local food systems in New Zealand. The aim of this research is to investigate the Farmer's market system in the context of its dependence on oil and compare it with the conventional supermarket system.

I have read brief information about this Farmer's market branch in your official website where 27 stallholders are currently listed.

As a participant for this research, I would like to request the following information:

- How many stallholders normally participate during the summer/winter months?
- Among these stallholders, can you select at least 5 of them whose product range include any of the following: (1. Produce, 2. Bread & Pastries, 3. Meat Poultry & Eggs, 4. Dairy, 5. Fish & Seafood, 6. Spices, Oil, & Honey, 7. Deli)
- Please fill-up the separate data sheet attached for the questions about the selected stallholders.

The data collected is strictly confidential and will be used only for research purposes and will ONLY be accessible by the research group members below. Furthermore all information related to this study will be stored in a password protected hard-disk.

To assure anonymity, your personal and business details are encoded with a randomly-generated identification number and will be used in lieu of your name. In addition, any information about your participation is not disclosed to other participants and all published material on this study will be in aggregated and generalised format and the company will not be implicated in any way.

As a participant, you may withdraw anytime from this project and the information you have provided will be excluded from the results of the project. Moreover, you may also request the immediate deletion of any initial data that you have provided.

The project is being carried out as part of my PhD dissertation and it is under the supervision of the following researchers listed below. They will be pleased to discuss any concerns you may have about participation in the project. This project has been reviewed and approved by the Department of Mechanical Engineering and the University of Canterbury Human Ethics Committee Low Risk Approval process.

# College of Engineering

Department of Mechanical Engineering  
Tel: +64 3 364 2987 loc 46503  
www.mech.canterbury.ac.nz  
janice.asuncion@pg.canterbury.ac.nz



Thank you very much.

Yours,

Janice Asuncion  
PhD Candidate  
Department of Mechanical Engineering  
University of Canterbury

## Supervisory Team

Dr Susan Krumdieck  
Associate Professor  
Department of Mechanical Engineering  
University of Canterbury  
Tel: +64 - 3 - 364 - 2987 (loc 7249)  
susan.krumdieck@canterbury.ac.nz

Dr Rua Murray  
Senior Lecturer  
Department of Mathematics  
University of Canterbury  
Tel: +64 - 3 - 364 - 2987 (loc 8376)  
rua.murray@canterbury.ac.nz

Dr Shannon Page  
Lecturer  
Department of Environmental Management  
Lincoln University  
Tel: + 64 - 3 - 325- 3838 (loc 8115)  
shannon.page.@lincoln.ac.nz

Date Sheet: Farmer's Market Code: \_\_\_\_\_

Date: \_\_\_\_\_

Stallholder	Product Type (1. Produce, 2. Bread & Pastries, 3. Meat Poultry & Eggs, 4. Dairy, 5. Fish & Seafood, 6. Spices, Oil, & Honey 7. Deli)	Estimated quantity of products sold per week (In kg, volume measure, or number of pellets)	Number of vehicles used for the deliveries	Type of vehicles (Write for all vehicles) 1. Private car 2. Van or parcel delivery 3. Light lorry 4. Medium-sized lorry 5. With trailer)	Farm Location (or cite estimated distance from farm to the market)	Percentage of products that are local
1.						
2.						
3.						
4.						
5.						
6.						
7.						

## 4. Human Ethics Approval for the Surveys



### HUMAN ETHICS COMMITTEE

Secretary, Lynda Griffioen  
Email: [human-ethics@canterbury.ac.nz](mailto:human-ethics@canterbury.ac.nz)

Ref: HEC 2011/10/LR-PS

18 April 2011

Janice Asuncion  
Department of Mechanical Engineering  
UNIVERSITY OF CANTERBURY

Dear Janice

Thank you for forwarding to the Human Ethics Committee a copy of the low risk application you have recently made for your research proposal "Analysis of truck trip generation characteristics of groceries and convenience stores".

I am pleased to advise that this application has been reviewed and I confirm support of the Department's approval for this project.

With best wishes for your project.

Yours sincerely

pp 

Dr Michael Grimshaw  
Chair, Human Ethics Committee

## Appendix E: Christchurch Heavy Vehicles and Retail

### Christchurch Business and Employment Geodata

#### Industry Sector Classification Code

A Agriculture, Forestry and Fishing

B Mining

C Manufacturing

D Electricity, Gas, Water and Waste Services

E Construction

F Wholesale Trade

G Retail Trade

H Accommodation and Food Services

I Transport, Postal and Warehousing

J Information Media and Telecommunications

K Financial and Insurance Services

L Rental, Hiring and Real Estate Services

M Professional, Scientific and Technical Services

N Administrative and Support Services

O Public Administration and Safety

P Education and Training

Q Health Care and Social Assistance

R Arts and Recreation Services

S Other Services

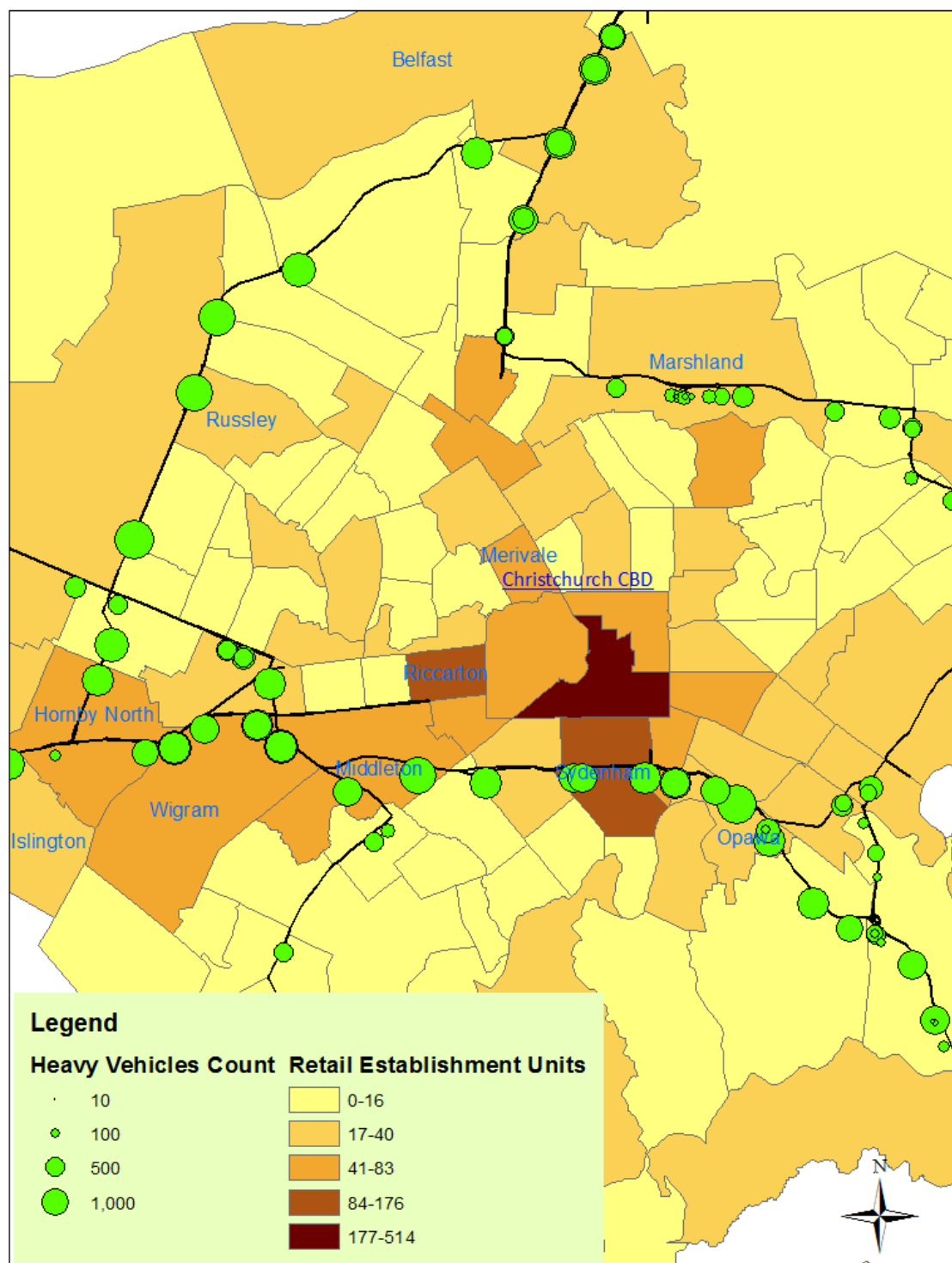


Figure E.1 : Christchurch heavy vehicles count of 2009 vs. Retail business units

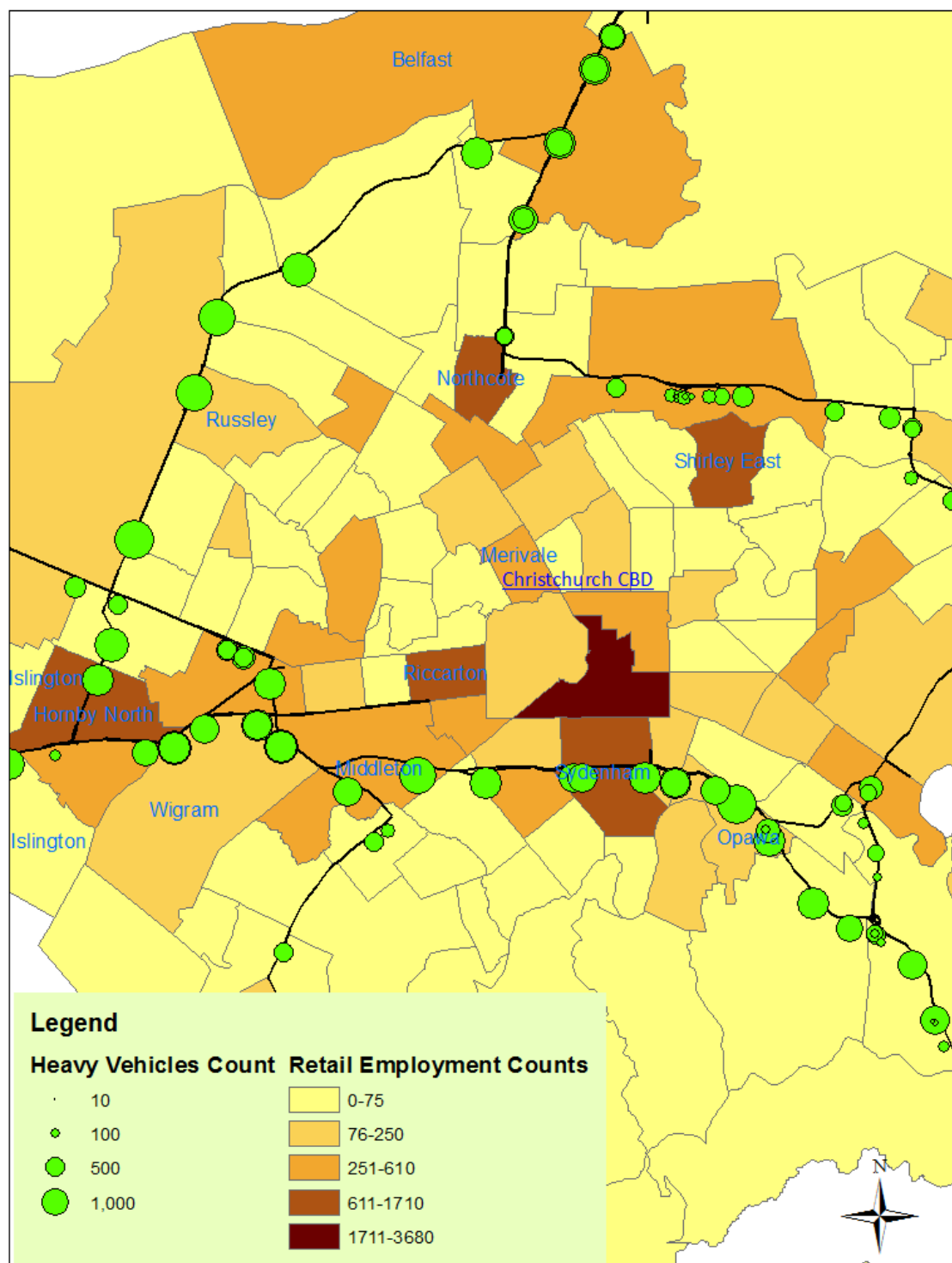


Figure E.2 : Christchurch heavy vehicles count of 2009 vs. Retail employment counts



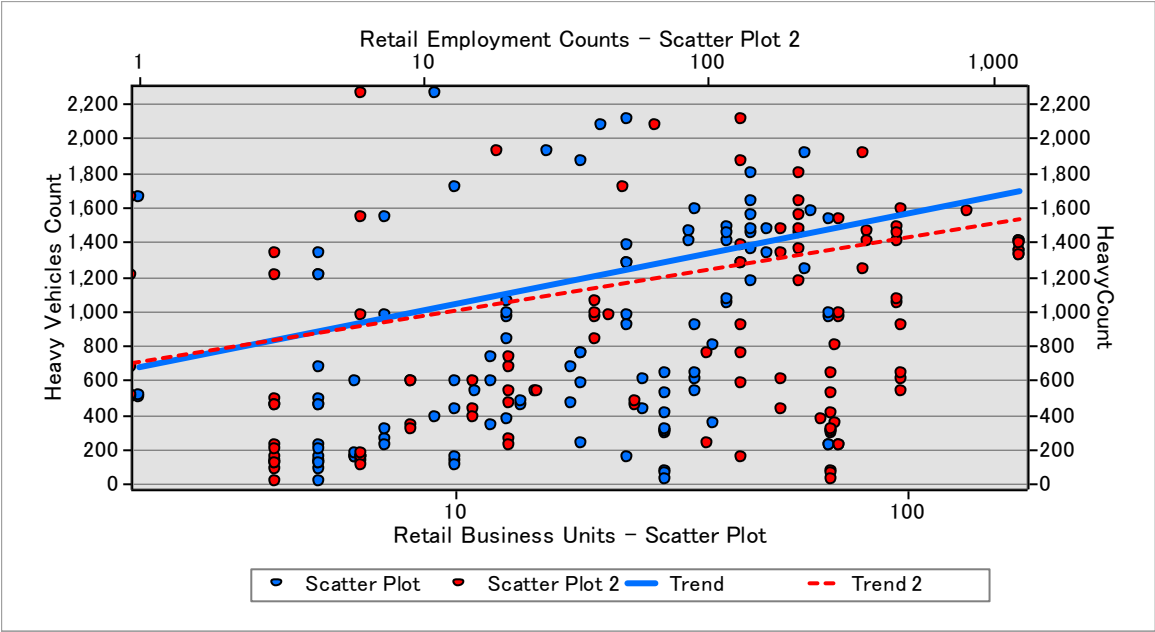


Figure E.3 : Christchurch heavy vehicle counts vs. Scatter plots of retail sector